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GEOPHYSICAL INVESTIGATIONS IN THE IONE AREA, AMADOR, SACRAMENTO, AND CALAVERAS COUNTIES, CALIFORNIA

1975

CALIFORNIA DIVISION OF MINES AND GEOLOGY

SPECIAL REPORT 117

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Special Report 117

GEOPHYSICAL INVESTIGATIONS IN THE IONE AREA, AMADOR, SACRAMENTO, AND CALAVERAS COUNTIES, CALIFORNIA

By

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1975

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ABSTRACT

The Ione area in western Amador County and adjoining parts of Sacramento and Calaveras Counties, California, contains important resources of clay, silica sand, and lignite. The California Division of Mines and Geology began a geophysical investigation in the Ione area in 1962 to provide basic data for use in studies of the geology and in exploration for mineral commodities in the Ione district and other potentially productive areas in the foothill belt of the Sierra Nevada. The investigation consisted primarily of a reconnaissance gravity survey but included tests of the electrical resistivity, magnetic, and seismic refraction methods. Additional data were provided by three core holes drilled to basement rock by the Division of Mines and Geology and the U.S. Bureau of Mines during the course of the study.

The basement rocks in the Ione area consist chiefly of steeply dipping greenstone of the Logtown Ridge Formation and slate of the Mariposa Formation, both of Jurassic age. Nearly flat-lying Tertiary sedimentary rocks, including the Ione, Valley Springs, and Mehrten Formations, were deposited on a fairly rugged erosion surface developed on the basement rocks. The commercially important clay, sand, and lignite deposits are found in the Ione Formation of Eocene age.

The residual gravity map shows a long, narrow, negative anomaly which extends about 20 miles from near Michigan Bar on the north to the Buena Vista Peaks area on the south. This negative anomaly is interpreted as a pre-Ione valley system in the basement rocks which was subsequently filled with relatively low-density sediments.

A contour map of the basement surface was constructed using basement elevations from drill hole information and seismic data supplemented by gravity data. The known lignite deposits are shown to be associated with the margins of the buried basin. The results from three core holes drilled on the basis of the geophysical work in relatively unexplored parts of the Ione basin have confirmed the presence of thick sequences of Tertiary sedimentary rocks including unexploited deposits of clay, sand, and lignite.

Magnetometer data were found to be effective for locating serpentine in the basement rocks and volcanic units of the Mehrten Formation. Resistivity soundings, however, were only marginally successful in identifying lignite beds.

The new information obtained as a result of this study, particularly the basement contour map and data from the three drill hole logs, should prove to be of value in future exploration for some of the mineral deposits in the Ione area.

GEOPHYSICAL INVESTIGATIONS IN THE IONE AREA, AMADOR, SACRAMENTO, AND CALAVERAS COUNTIES, CALIFORNIA

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INTRODUCTION

Important resources of clay, silica sand, and lignite are found in a 200-square-mile area in the vicinity of the town of Ione in western Amador County and adjoining parts of Sacramento and Calaveras Counties, California (figure 1). These nonmetallic mineral commodities are produced from the Ione Formation of Eocene age, which crops out in a discontinuous belt about 24 miles long and 8 miles wide in the foothills along the western margin of the Sierra Nevada. Placer gold, laterite, copper, zinc, and building stone have also been produced in the district.

The California Division of Mines and Geology undertook an investigation in the Ione area in 1962 to provide basic geophysical data for use in studies of the geology and to enhance exploration for mineral deposits in the district. The investigation consisted primarily of a reconnaissance gravity survey but included resistivity soundings, ground magnetometer lines, and seismic refraction depth determinations. Magnetic susceptibility and density measurements were made on rock samples in the aboratory. Field work was done during intervals between February 1962 and October 1967. During the course of this investigation, three core holes were drilled by the U. S. Bureau of Mines in the Ione basin area in a cooperative program with the Division of Mines and Geology.

The authors gratefully acknowledge the help of the following individuals: Frank de Angelis and Joseph de Angelis of the former American Lignite Products Company (now a division of Interpace Corporation), who provided logs from several drill holes and data on lignite deposits in the Ione area; Russell J. Hayden of the FMC Corporation who furnished information on the results of lignite exploration in the district; and William Craven and W.D. Anderson of Interpace Corporation who provided much valuable information about the geology of the area.

Leigh Readdy and Arthur Smith of the California Division of Mines and Geology staff assisted the authors during various phases of the field work. Gordon Chase and Bert Jeffries, also of the Division staff, were responsible for most of the seismic field work and interpretation. C.T. Weiler, at the time with the U.S. Bureau of Mines, supervised the drilling project. Some regional gravity data in the area was provided by Howard Oliver of the U.S. Geological Survey (written communication, 1966).

GEOLOGY

Geologic investigations of the Ione area date back to the late 19th century. A stratigraphic section of rocks at Buena Vista Peak and a general account of the geology of Amador County was given by Mason (1881, p. 125-126). The Buena Vista-Ione area was shown on maps in the Jackson folio (Turner, 1894). Lindgren (1911, p. 21-28, 196-197) delineated the courses of the Tertiary rivers of the western Sierra Nevada and showed that they carried the sediments that now compose the sedimentary rocks of the Ione Formation. Allen (1929, p. 347-348) studied the Ione Formation and restricted it by excluding the upper rhyolite member that had been ncluded by Turner. Stearnes and others (1930) published a regional geologic map, but the part showing the Ione area was largely taken from Turner. Piper and others (1939) named and described the Valley Springs and Mehrten Formations and published a geologic map of the area. The pre-Tertiary rocks were more completely described and defined in a report on manganese by Taliaferro (1943, p. 280-286, 306-307). Bates (1945, p. 1-38) studied the commercial clays of the Ione area. The Buena Vista area was mapped in detail and the Ione Formation was described in a report by Pask and Turner (1952) on the geology and clay resources of the Ione Formation. The ages of the Tertiary sedimentary rocks have been discussed in studies by Dickerson (1913, p. 257-298, and 1916, p. 387-417), Clark (1921, p. 161-165), Clark and Vokes (1936, p. 851-878), and Dalrymple (1963).

The geologic map accompanying this report (plate 1) is chiefly a compilation of earlier work. It includes a part of an unpublished map of the Sutter Creek 15-minute quadrangle by Taliaferro (1949), which was slightly modified during this investigation. The geologic units were grouped for the purpose of this report as follows: 1) Basement complex, composed of the Calaveras Formation, Amador Group, Mariposa Formation and granitic intrusive rocks (serpentine, in reality a part of the basement complex, is shown on the map as a separate unit); 2) Tertiary sedimentary rocks, composed of auriferous gravels, pre-Ione sedimentary rocks, the Ione Formation, the Valley Springs Formation, and the Mehrten Formation; and 3) Quaternary deposits.

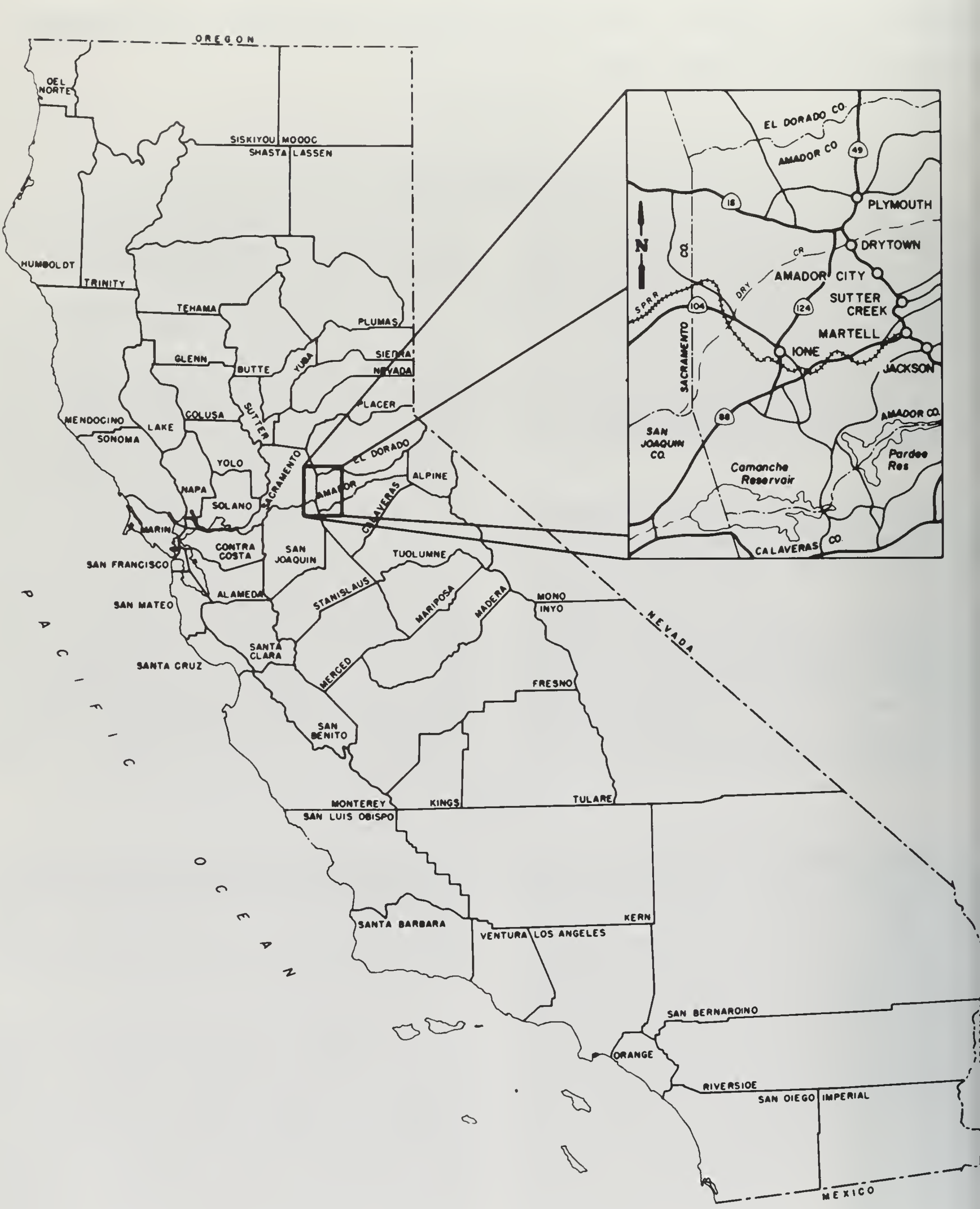

Figure 1. Map showing location of the Ione area.

The basic rock units in the Ione area may be urther grouped into two major divisions: the asement complex (unit 1) and the overlying edimentary rocks (units 2 and 3). The basement omplex is composed of highly folded, metamorhosed volcanic and sedimentary rocks and related ntrusive rocks of pre-Cenozoic age. The later edimentary rocks overlie the basement complex ith marked angular unconformity. These rocks are early flat-lying but show a slight southwestward ip, probably the result of tilting of the Sierra evada during Tertiary time.

ASEMENT COMPLEX

The basement complex consists of metamorphic ocks of the Calaveras Formation, Amador Group, ariposa Formation, intrusions of plutonic rocks, nd serpentine. The Calaveras Formation is the ldest rock unit in the area and includes all known re-Mesozoic rocks. It consists chiefly of ecrystallized limestone, metachert, and quartzite. he Calaveras Formation crops out on the eastern nd northeastern edges of the area covered by this eport, where these rocks lie unconformably below ocks of the Amador Group.

Taliaferro (1943, p. 282-284) divided the mador Group into two formations, the Cosumnes nd the Logtown Ridge. In most of the area covered y this report, the Amador Group consists almost ntirely of greenstone (metamorphosed andesitic nd basaltic lavas) and amphibole schist of the ogtown Ridge Formation. A metamorphosed reenish sandstone, which may be part of the osumnes Formation, was encountered in the botom of drill hole 1967-1 in the NE 1/4 Section 30, T. N., R. 9 E. (see plate 1 and figure 7). Rocks of e Amador Group generally have a moderate-to-teep dip and crop out in long northwest-trending elts separated by bands of slate of the Mariposa ormation. The prominent ridge north of Jackson alley and west of Ione is composed of greenstone f the Logtown Ridge Formation. The Amador roup is believed to be late Middle and early Late urassic (Taliaferro, 1943, p. 284). In this area, it is n sharp conformable contact with the overlying ariposa Formation.

The Mariposa Formation, assigned by aliaferro (1942, p. 77-81) to a Late Jurassic age, is omposed of black slate with a few lenses of etamorphosed sandstone and conglomerate. It is enerally less resistant to erosion than the Logtown idge Formation and commonly underlies gentle alleys between ridges of the more resistant greentone. In a fairly extensive area north of Ione and irectly south of Irish Hill, the slate of the Mariposa ormation has been altered, possibly hydrotherally, to a sericitic clay. In this general area, clay is ined from both the Ione and Mariposa Formations r ceramic uses.

Plutonic igneous rocks that range in comosition from gabbro to granodiorite intruded the other rocks of the basement complex. The igneous rocks appear to be associated with the Sierra Nevada batholith and were probably intruded in Late Jurassic or Early Cretaceous time. Serpentine is a common intrusive rock of the foothill belt; in this area, it occurs in a nearly continuous narrow northwest-trending belt extending southward from the vicinity of Willow Springs School to the Pardee Reservoir.

TERTIARY SEDIMENTARY ROCK SEQUENCE

Unconformably overlying the basement rocks is a series of gently dipping sedimentary rocks which has been divided into unnamed pre-Ione beds and the Ione, Valley Springs, and Mehrten Formations.

The pre-Ione beds are described by Pask and Turner (1952, p. 15-16). They consist of beds of sandy clay, sandy silt, and clay, commonly green. Their mineral composition indicates that the source rocks sustained less severe weathering or more rapid erosion than occurred during Ione time. These beds do not crop out but have been encountered in many drill holes in the Buena Vista area, where the maximum thickness penetrated was 131 feet. Pask and Turner (1952, p. 16) considered the pre-Ione beds tentatively to be Eocene. Drill holes 1967-1 and 1967-3 (see figure 7) encountered strata of gray sandstone and greenish clay below the Ione Formation that may correspond to pre-Ione beds. Pre-Ione beds were not recognized in drill hole 1967-2, southwest of Buena Vista Peaks.

The Ione Formation was originally named by Lindgren (1894, p. 3). Turner (1894) described the type section near the towns of Ione and Buena Vista. The formation was deposited on an irregular, deeply weathered erosion surface developed on the older rocks. It consists of alternating lenticular beds of sandstone and claystone with lenses of brown carbonaceous claystone and lignite. The beds are commonly white but locally may be colored red, yellow, or purple by mineral staining.

Pask and Turner (1952, p. 16) divided the Ione Formation into upper and lower members in the Buena Vista region: the lower member contains most of the commercial clay in the area and is characterized by the rarity of chlorite, biotite, and certain clay minerals; the upper member is predominantly sandy. The writers were unable to recognize this subdivision in drill hole 1967-2, southwest of Buena Vista Peaks, where practically the entire section is sandy. Dickerson (1916, p. 397) reported marine Eocene fossils from a quarry in Ione sandstone 3 miles southeast of Buena Vista. The presence of these fossils suggests occasional invasions of the sea into this predominantly continental environment of deposition. The sandstone beds are commonly cross-bedded and usually occur in relatively narrow channels, which indicates that deposition occurred in stream beds or river channels (Allen, 1929, p. 357-358). The silts and clays were deposited in quiet water, probably in lakes or

Photo 1a. Greenstone, of the Logtown Ridge Formation, exposed in quarry about 3 miles southwest of Ione.

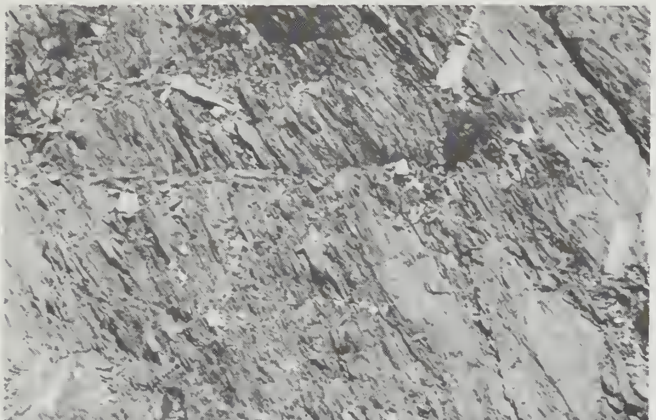

Photo 2. Close-up view of slate of the Mariposa Formation in a roadcut showing slaty cleavage dipping to the northeast at about 70 degrees. The roadcut is on U. S. Highway 88, about 2 miles southwest of Ione.

Photo 1b. Agglomeratic greenstone of the Logtown Ridge F mation which was quarried for use as riprap on Caman Dam.

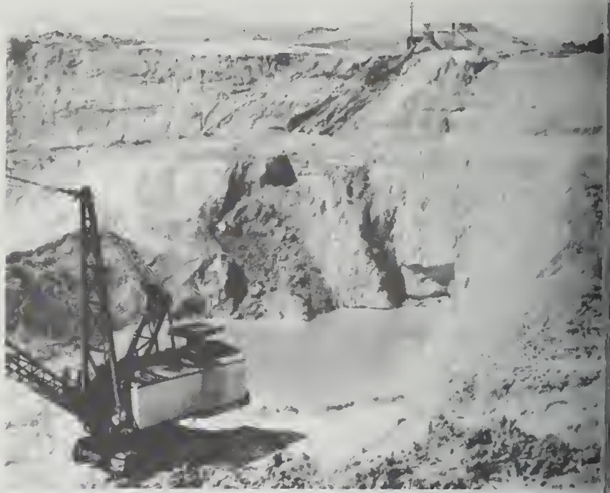

Photo 3a. Interpace Corporation sandpit in the Ione Forma about 1 mile southwest of Ione (view west).

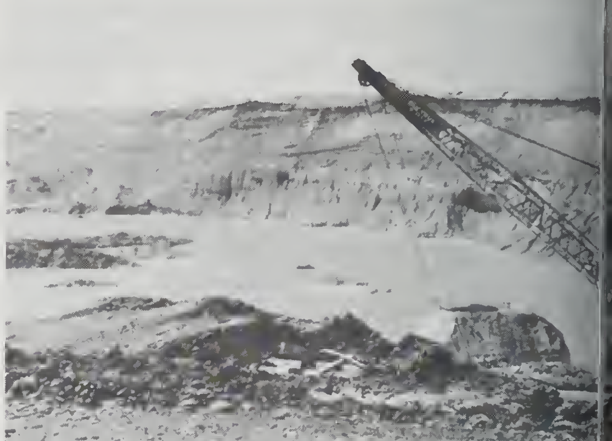

Photo 3b. Interpace Corporation sandpit in the Ione Form about 1 mile southwest of Ione (view southwest). Note large-scale cross bedding in the fluvial deposits expose the pit walls.

oto 4. Tuffaceous sandstone of the Valley Springs Formation posed in a roadcut about 6 miles northwest of Ione.

oto 6. Andesite cobble conglomerate of the Mehrten Forᐧ ation exposed in a roadcut about 2 miles southwest of Buena sta.

Photo 5. Buena Vista Buttes, a prominent landmark in the Ione area, as seen from the southwest. The Buttes consist of relatively resistant sandstones and tuffs of the Valley Springs Formation.

Photo 7. Interpace Corporation Indian Hill clay plant, located about 3 1/2 miles northwest of Ione.

Photo 8. View of an Interpace Corporation sand plant, about 1 mile southwest of Ione, showing the tailings disposal pond in the foreground. *Photo by William B. Clark.*

lagoons. The lignite was derived from altered vegetation that grew near the margins or within these bodies of water.

The thickness of the Ione Formation varies considerably throughout the area. Piper and others (1939, p. 80) suggest a maximum thickness of about 450 feet. In drill hole 1967-2, southwest of Buena Vista Peaks, however, the total thickness was found to be 630 feet (figure 7).

The Valley Springs Formation is composed of conglomerate, sandstone, tuff, and claystone derived principally from rhyolitic volcanic material (Piper and others, 1939, p. 71-80). The best exposures of this formation are found on Buena Vista Peaks, where it is 440 feet thick. The thickness varies considerably throughout the area; for example, in drill hole 1967-2, only 50 feet were encountered (figure 7b). Rocks from this formation have been dated by Dalrymple (1964, p. 6) as middle Miocene on the basis of potassium-argon dates of 19.9 to 22.8 million years.

The Mehrten Formation unconformably overlies the Valley Springs. It is composed principally of sandstone, siltstone, and andesite cobble conglomerate. These beds were described in detail by Piper and others (1939, p. 61-71). The thickness of the Mehrten Formation ranges from a thin band to about 200 feet in the area of this investigation. At the type section north of the Mokelumne River, the formation is 183 1/2 feet thick (Piper and others, 1939, p. 62). Dalrymple (1963, p. 388, 1964, p. 10) concluded that the Mehrten Formation is most likely middle and late Miocene to late Pliocene, based on potassium-argon age dates obtained from latite flows found in a section from the Sierra Nevada.

QUATERNARY DEPOSITS

In the Buena Vista area, terrace deposits of coarse-grained conglomerate were reported by Pask and Turner (1952, p. 21-22) to be as much as 150 feet above the present level of Jackson Creek. These beds contain pebbles and cobbles of white quartz and andesite and metamorphic rocks of the type found in the Calaveras Formation in a matrix of greenish-brown to red-brown sandy clay.

Alluvium is found along the present stream channels and their tributaries principally in Jackson Valley, Ione Valley, and the area north and west of Carbondale. The alluvium is generally buff to brown, silty, clayey sand, and sandy conglomerate. Drill holes in Jackson Valley have encountered 25 to 50 feet of this material (Pask and Turner, 1952, p. 22).

STRUCTURE AND GEOLOGIC HISTORY

The metasedimentary and metavolcanic rocks of the basement complex are exposed in long northwest to locally northward-trending isoclinal folds that dip steeply northeastward. Two ages metamorphism - are indicated, one affecting tl Paleozoic rocks and another involving bo Paleozoic and Mesozoic rocks. The latter w associated with folding which began in the La Jurassic and continued into the Cretaceo (Taliaferro, 1943, p. 285-286).

The area was reduced by erosion during La Cretaceous and early Tertiary time to a surface moderate relief. Differential erosion of the beds the basement complex prior to the deposition of tl Tertiary rocks appears to have resulted in the fo mation of a trellis-type drainage pattern. Present di ferences in elevation of the erosion surface at tl top of the basement complex are in excess of 4(feet in the Buena Vista area.

The lower Tertiary sediments were deposit on the eroded surface of the basement comple These Tertiary beds are still essentially flat lyin showing only a slight dip to the south and west. N folding of these rocks can be seen; the disco formable relationships between the Ione, Vall Springs, Mehrten, and younger deposits is the res of renewed uplifts of the Sierra Nevada. Dow bowing of parts of the Ione Formation in the deep parts of the basin of deposition was probably caus by compaction of the sediments, particularly of tl clay and the plant material that formed lignite.

ECONOMIC GEOLOGY

The principal mineral deposits of the Ione ar are shown on plate 1. Of all the mineral co modities produced, clay, silica sand, and ligni have the greatest economic significance.

The Ione area has yielded about a third of t fire clay produced in California since the mining this commodity began about 1860 (Cleveland, 195 p. 136). More than 60 clay pits are distributed in t area between Carbondale and Buena Vista. Most the fire clay is used in heavy clay products, but significant amount is used in refractory product

The U.S. Bureau of Mines conducted an i vestigation in the Ione-Carbondale area duri World War II to determine the suitability of the Io clays for the production of alumina (Johnson a Ricker, 1948, p. 1). Seventy holes aggregating 8,8 feet were drilled in areas about 2 miles northwest Ione and near Carbondale. Analysis of a compos sample of the clay showed the recoverable alumi (Al_2O_3) to be 23.6 percent and the iron oxi (Fe_2O_3) content to be 2.8 percent.

Because the clays were deposited in lo topographic depressions, the clay deposits a discontinuous. They commonly consist of clay-sa mixtures with a sand content that ranges from a f percent to 60 percent. The deposits range thickness from a few feet to 30 feet. The clays of t Ione Formation are kaolinitic whereas the resid clay of the Mariposa Formation south of Irish H

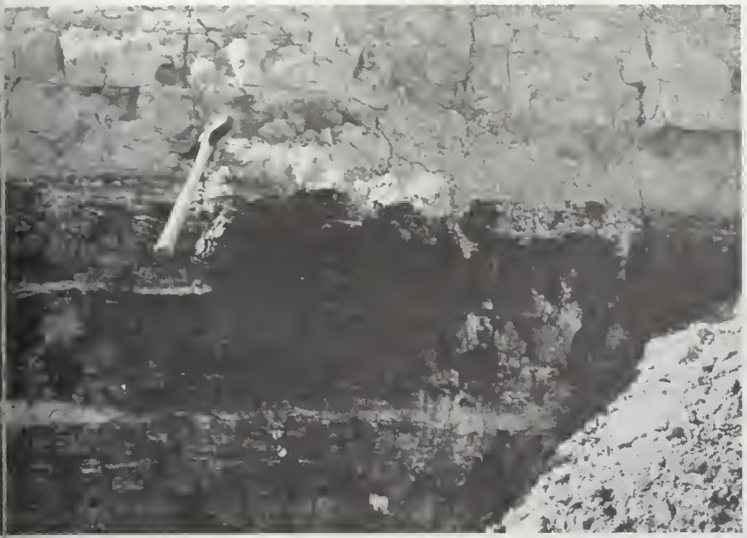

Photo 9. A lignite bed overlain by clay in the Ione Formation. This exposure is in a pit about 1 1/2 miles southeast of Buena Vista.

to 10. The Interpace Corporation lignite plant ut 1 mile south of Buena Vista. This view is th toward Buena Vista Buttes (compare with to 5). Since the photo was taken in 1952, the ngs pile in the foreground has increased in and now tends to obscure the view of the nt. *Photo by William B. Clark, 1952.*

Photo 11. The Interpace Corporation laterite pit located about 4 miles northwest of Ione. The laterite is overlain by light-colored clay and sand of the Ione Formation exposed in the cut on the hill in the background.

Photo 12. Close-up of the laterite exposed in the shown in photo 11. The pencil in left middleground dicates scale.

Photo 13. The Newton copper mine (inactive), located about 3 miles southeast of Ione and south of U. S. Highway 88.

sericitic. Open pit methods are now used to mine ie clays although in the past selective underground iining was used for some of the highly refractory lays.

Silica sand, a basic raw material for the glass inustry, is also mined from the Ione Formation in the ne area. The deposits being mined are generally ixtures of clay, quartz, and feldspar and a small oportion of heavy minerals. Sand grains are comonly coated with iron oxide. Some deposits are ined for both the clay and the sand content. The avy minerals are usually removed in processing e sand.

The chief use of the silica sand produced in the ne area is in the making of glass containers. owever, because a mill product can meet the ecifications for flint glass, the silica sand could so be used for the manufacture of plate glass (Gay, 57, p. 554).

Lignite occurs in the Ione Formation in nearly it-lying lens-shaped bodies as much as 24 feet ick interbedded with the claystone and sandstone. ie lignite may be relatively pure, or it may be inrmixed with clay. At the Interpace mines near ne, the lignite is mined by open pit methods, but ost of the older lignite mines were underground erations. The locations of the known important nes are shown on plate 1.

Lignite has been mined in the Ione area since rly in the 1860s (Goodyear, 1877, p. 79). Acrding to Carlson and Clark (1954, p. 160), the al recorded production in the district before 1903 s about 247,000 tons, valued at $358,000. Most this lignite was used locally for fuel. Between 03 and 1947, there was only sporadic production lignite because of the competition from petroleum oducts.

After it was found that the lignite contains a gh proportion of wax suitable for industrial uses, lignite mining was resumed on a continuous basis in 1948 by the American Lignite Products Company at Ione. The Ione lignites are the only ones in the United States being utilized for the commercial production of montan wax. Details on the method of extraction of this wax are given by Jennings (1957, p. 158-159).

Gold, laterite, copper, zinc, and building stone are other mineral products from the Ione area. Placer gold was discovered in the early 1850s (Mason, 1881, p. 265). Mining of the alluvial gold deposits in the area was most active between 1855 and 1885.

Laterite, red or buff in color and high in aluminum and iron oxides, is exposed in the Jones Butte area northwest of Ione and on the greenstone ridge north and south of Jackson Creek. Small quantities of laterite mined near Ione have been utilized in making cement.

Several copper-zinc deposits have been found in the basement rocks in the Ione area. In particular, the Newton mine in Section 28, T. 6 N., R. 10 E., M.D.B.M. about 3 miles southeast of Ione, and the Penn mine in Sections 3 and 4, T. 4 N., R. 10 E., and Section 33, T. 5 N., R. 10 E., were important producers of copper and zinc ores. None of the mines is active at the present time. The "ore bodies" are replacement deposits consisting of pyrite, chalcopyrite, sphalerite, and other sulfides and usually contain recoverable amounts of gold and silver.

Sandstone from the upper part of the Ione Formation and red-and-white rhyolite from the Valley Springs Formation in the Buena Vista Peak area have been quarried for local use as building stone. Greenstone from the hill northwest of Buena Vista was quarried for use as riprap in the construction of Camanche Dam on the Mokelumne River.

GEOPHYSICAL SURVEY

ELD METHODS AND REDUCTION OF DATA

Approximately 270 irregularly distributed avity stations were occupied in the Ione area at nch marks, surveyed elevation points, and photo evation points from the U.S. Geological Survey 7 2-minute preliminary topographic maps. Some evations were obtained by means of a level and a v by altimeter. With the exception of the altimeter ints and those obtained photogrametrically, most the station elevations are probably determined to accuracy of about 1 foot. Some of the altimeter d photogrametric points may be as much as 5 feet error, but checks indicate that this large an error unusual. The average station density is about 1 1/2 tions per square mile, with the greatest concentration of stations being in the Ione and Jackson Valley areas where the greatest number of elevation points is available.

Worden gravity meter No. 558 with a sensitivity of about 0.01 milligal per vernier unit was used for the survey. Gravity readings at all stations were tied to bases at U.S. Coast and Geodetic Survey (now National Ocean Survey) bench mark L-795 at Ione and U.S. Geological Survey bench mark 3 M at Buena Vista. Bench mark L-795 is one of the gravity bases in the California Division of Mines and Geology statewide network (Chapman, 1966, p. 30).

The values of observed gravity were corrected for drift, latitude, and elevation. To minimize the effects of topographic features on the gravity anomaly values, the Bouguer and elevation corrections were made to a local datum level of 400 feet. This is approximately the highest elevation reached by the basement rocks in the immediate Ione basin area. All stations below the datum were raised to this level using a density of 1.9 g/cm^3, the value adopted for the Tertiary sedimentary rocks. All stations above 400 feet were reduced to this level using a density of 1.9 g/cm^3 for those stations on Tertiary rocks and 2.9 g/cm^3 (density adopted for greenstone) for those stations on basement rocks. Finally, all stations were reduced to sea level using a density of 2.9 g/cm^3.

Terrain corrections for most stations were found to be less than 0.10 milligal through Hammer Zone J (Hammer, 1939, p. 184). Corrections which exceeded 0.10 milligal were made for a total of 17 stations located mostly in the vicinity of the higher elevations around Buena Vista Peaks.

Resistivity soundings were made using direct-current equipment and porous pots for potential electrodes. A Wenner electrode configuration (Dobrin, 1960, p. 349) was used, and the depth of current penetration was controlled by varying the electrode spacing. The direct current was reversed and the readings averaged to eliminate the effects of natural currents.

Magnetic readings were taken with a Jalander flux-gate magnetometer. Temperature and diurnal effects were removed by repeated readings at a base station.

Seismic refraction data were obtained with Midwestern portable seismic refraction equipment which recorded the output of 12 geophones on photographic paper. The geophone spacing ranged from 50 to 100 feet, and energy was supplied by small dynamite charges buried at depths of 3 to 6 feet.

PHYSICAL PROPERTIES

Density and magnetic susceptibility measurements were made on a few samples of the most common rock types in the Ione area and are listed in table 1.

Samples 1 through 6 are greenstone from the Amador Group and have a range of density values between 2.80 and 2.97 g/cm^3. Sample 7, with a density of 2.67 g/cm^3, is from the granitic intrusive rocks of the basement complex. The eight remaining samples of the basement complex are from the Mariposa Formation and fall between 1.97 g/cm^3 for a sample altered to clay and 2.66 g/cm^3 for fairly fresh micaceous schist. The samples of dry Ione sandstone and clay range between 1.83 and 2.15 g/cm^3, except for one iron oxide-cemented sample which was 2.42 g/cm^3. Dry samples of the Valley Springs and Mehrten Formations are in the density range of 1.82-1.88 g/cm^3; corresponding water-saturated samples, 2.05-2.09 g/cm^3. The one sample of lignite tested had a density of 1.20 g/cm^3.

Table 1. Rock property measurements — Ione area

Sample no.	*Description*	*Density (g/cm^3)*	*Magnetic susceptibilit (emu/cm^3*
Basement complex			
1	Amphibole schist	2.80	5.2×10^{-5}
2	Pale green agglomerate	2.82	5.2×10^{-5}
3	Green dense agglomerate or flow	2.91	
4A	Pale green dense agglomerate	2.95	
4B	Pale green dense agglomerate	2.97	
5	Pale green somewhat altered agglomerate	2.80	
6	Green dense andesite	2.88	
7	Quartz porphyry	2.67	
8	Gray slate	2.54	6.0×10^{-5}
9	Gray slate	2.57	
10	Pale gray micaceous schist with quartz lenses	2.66	
11	Sheared graywacke	2.54	
12	Altered whitish-gray slate	2.45	
13	Altered whitish-gray slate	2.50	
14	Gray clay (altered slate)	1.97 (wet)	
15	Gray clay (altered slate)	1.99 (wet)	
Ione Formation			
16	White sandy clay	1.98 (dry)	
17	White sandy clay	1.83 (dry)	$9.0 \times 10^{-}$
18	Yellow sandstone with limonite cement	2.42 (dry)	$5.0 \times 10^{-}$
19	Yellow sandstone	2.15 (dry)	
20	Lignite	1.20 (dry)	very sm
Valley Springs Formation			
21	Buff rhyolite tuff		$5.2 \times 10^{-}$
22A	Buff rhyolite tuff	1.86 (dry)	
22B	Buff rhyolite tuff	2.06 (wet)	
23A	Buff rhyolite tuff	1.88 (dry)	
23B	Buff rhyolite tuff	2.09 (wet)	
Mehrten Formation			
24A	Grayish-brown tuffaceous sandstone	1.82 (dry)	$270 \times 10^{-}$
24B	Grayish-brown tuffaceous sandstone	2.05 (wet)	
25A	Grayish-brown tuffaceous sandstone	1.84 (dry)	
25B	Grayish-brown tuffaceous sandstone	2.08 (wet)	

Because the number of specimens tested is t small to provide an adequate sampling of the wh area under consideration, two density profiles we utilized to obtain independent values of the densit of the Ione and Valley Springs Formations followi the method outlined by Nettleton (1940, p. 57). this procedure, the gravity values for stations acr a topographic feature are reduced, including terr effects, for a number of different density values. T value that shows the least correlation w topography should be the proper density for use the reductions. One of the profiles was over a hill sedimentary rock of the Ione Formation; the ot was over a hill composed of rocks of both the Ic and Valley Springs Formations. In both profiles, l least correlation with topography was found fo density of about 1.8 g/cm^3. However, because average of the measured density values is close to g/cm^3, a value of 1.9 g/cm^3 was adopted for gravity reductions.

The magnetic susceptibility measurements were ade on a Geophysical Specialties Company bridge, hich was made available through the courtesy of r. S.G. Sargis, Columbia Geneva Division, United ates Steel Corporation. The measurements of the mples of the basement complex and the Ione and lley Springs Formations all fall in the range of 5 x $^{-5}$ to 10 x 10^{-5}emu/cm^3, indicating low values of agnetic susceptibility with no great differences ong the rock types. The one sample of tuffaceous ndstone from the Mehrten Formation gave a value 270 x 10^{-5}emu/cm^3, which indicates a strongly agnetic rock, much more so than any of the other cks tested. Serpentine, commonly a very magnetic ck, is present in the exposed basement rocks east Ione. Hand specimens of this rock type were und to be very magnetic, but no susceptibility easurements were made. However, DuBois (1963, 271) found an average value of 420 x $^{-5}$emu/cm^3 for a suite of serpentine specimens llected near Mariposa, in the foothill belt, about miles south of Ione.

ALYSIS OF DATA

avity Maps

Figure 2 is a Bouguer gravity map of the Ione ea contoured at a 2 milligal interval. The most nspicuous features of the gravity field are the nd of the contours of about N. 30° W. and a gional gradient of about 5 milligals per mile, wnward toward the northeast. This strong gional gradient is caused in part by the presence a positive gravity anomaly just west of the map ea in the Sacramento Valley. It is also caused in rt by a thickening of the earth's crust under the rra Nevada (Oliver, Pakiser, and Kane, 1961, p. 69). The steepness of the gravity gradient tends to scure local anomalies in the Ione area, but one teworthy feature is the prominent negative omaly which forms a northeast-trending saddle in southern part of the map area, just north of the kelumne River. This feature shows up well cause it is nearly normal to the regional trend.

To study the local features of the gravity map, it necessary to remove the steep regional gradient. is was accomplished by utilizing seven gravity ofiles which cross the area (see plate 1); the gional gravity trend was determined on each ofile by using stations located on or near basement cks, then a "smoothed" regional map was prepared m these results. Residual gravity values were obned by taking the difference between the observed d interpolated regional values at each station. ate 1 shows the resulting residual gravity contours perimposed on the geologic map of the Ione area.

The principal anomaly shown by the residual ap is a prominent gravity low with a trend of about 30° W. for most of its length, centered aproximately over the known basin structure west of e towns of Ione and Buena Vista and east of Carndale. This gravity low extends for about 20 miles northwest from near Buena Vista Peaks to a point near Bridge House. At each end, extensions of the anomaly turn sharply toward the southwest. In the area southwest of Buena Vista Peaks, the anomaly is prominent and corresponds to the "saddle" mentioned in the discussion on the Bouguer gravity map. From a point northwest of Ione near Indian Hill, the anomaly amplitude increases both northwest and southeast.

The gravity low is flanked on both sides by positive anomalies. On the west, the positive anomaly is over discontinuous outcrops of greenstone of the Logtown Ridge Formation. Between Jones Butte and Jackson Creek, this greenstone forms prominent hills; but, northwest of Jones Butte, no outcrops of greenstone are known for a distance of about 9 miles until it reappears near Bridge House, just south of the Cosumnes River. The presence of the buried greenstone ridge is suggested, however, by the nearly continuous positive gravity anomaly in this area. There are three distinct interruptions in this positive anomaly trend: one southeast of Bridge House, another in Jackson Valley, and the third southwest of Buena Vista Peaks. The positive gravity anomaly on the eastern side of the Ione basin passes very close to the towns of Ione and Buena Vista. It corresponds to exposed greenstone in most of the area north of Ione. A low-amplitude negative gravity anomaly, which also has a trend of approximately N. 30° W., is found east of Ione over exposures of Mariposa Formation.

On a smaller scale, there are several distinct negative gravity anomalies along the eastern edge of the Ione basin. The largest of these is about 2 miles southeast of Ione on the east side of the basin near a gravel delta mentioned by Pask and Turner (1952, p. 18). There are others in the areas where Jackson Creek, Sutter Creek, and Dry Creek leave basement rocks and enter the valley.

Because measurements indicate a distinct density contrast between basement rocks and the Tertiary sedimentary rocks, it is reasonable to assume that the main negative gravity anomaly is caused in large part by low-density sedimentary rocks in the Ione basin. This basin is now known from drill holes to be present most, if not all, of the distance between points southeast of Bridge House and southwest of Buena Vista Peaks. However, in this area the basement complex includes different rock types such as: greenstone (measured density range 2.80-2.97 g/cm^3); slate (measured density range 2.45-2.66 g/cm^3); intrusive igneous rocks (measured density of one sample of quartz porphyry 2.67 g/cm^3); and possibly rocks of the Cosumnes Formation. The relative abundance of these units varies from place to place; furthermore, near Irish Hill the basement rocks (slate) are known to be extensively altered to sericite. Thus, density contrasts within the basement rocks and possibly within the overlying Tertiary sedimentary rocks also undoubtedly have a significant effect on the gravity anomalies. All of these factors must be considered in any interpretation of the gravity data.

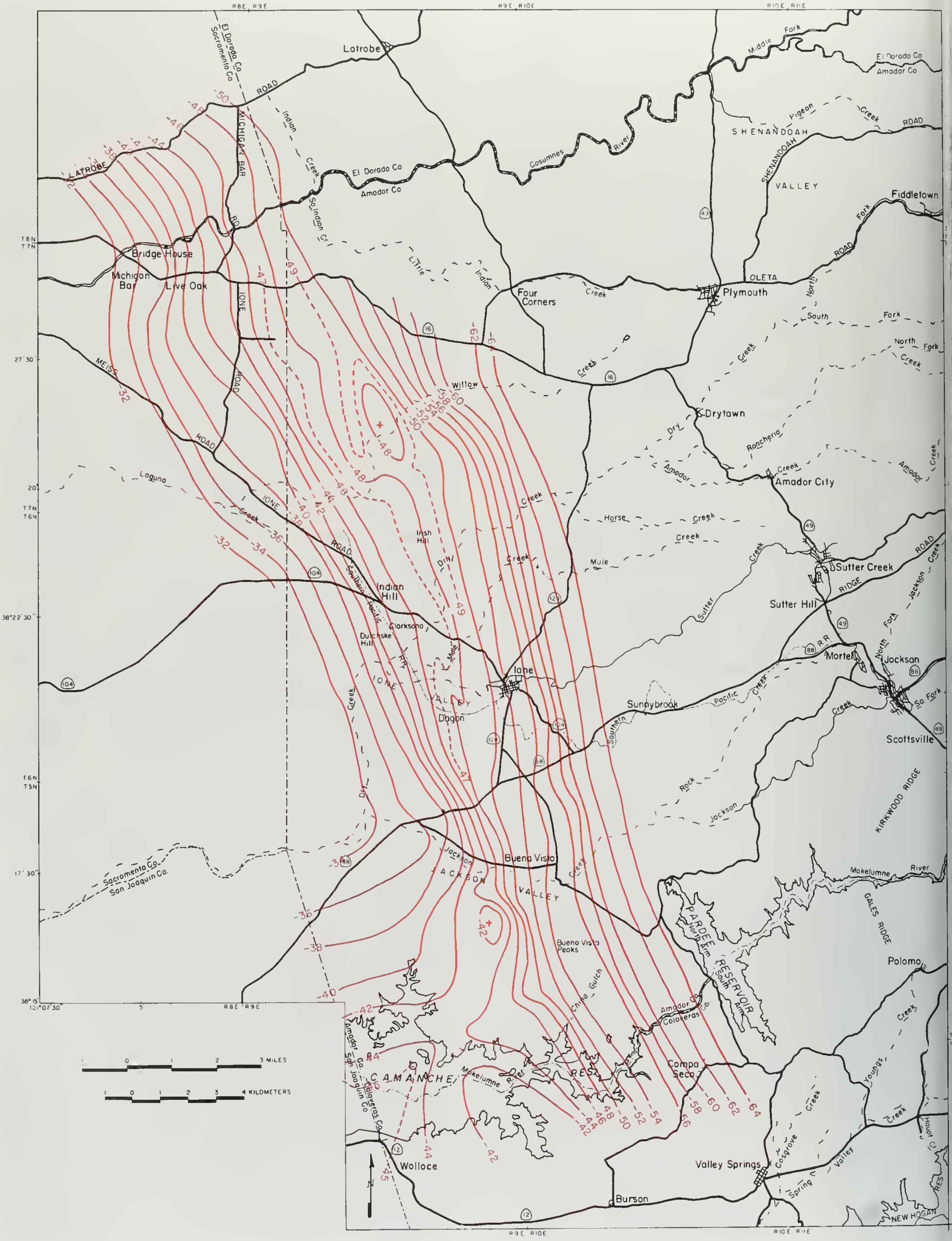

Figure 2. Bouguer gravity map of the Ione area.

With these limitations in mind, the gravity data ere used with the information from the drill holes d seismic data to investigate the configuration of e buried basement surface in the Ione area along e seven profiles A-A′ through G-G′ (plate 1).

The maximum gravity anomaly caused by a sin structure where the width of the basin is much eater than the depth can be calculated by the ouguer gravity formula for an infinite plate (obrin, 1960, p. 230) in which the gravity anomaly g is given by:

$$\Delta g = 2\pi b(\Delta\sigma t)$$

Where b is the universal gravitational constant, σ is the density contrast, and t is the average ximum thickness of anomalous density. Con- rsely, if the anomaly and density contrast are own, the thickness may be calculated. The use of is simple approximation is limited to structures ich have much larger horizontal dimensions than rtical; the more the structure deviates from a sim- e slab, the larger the error.

The gravity anomaly caused by a basin structure n also be calculated with greater accuracy from the tual cross section by means of a gravity graticule of e type described by Dobrin (1960, p. 258), as done this study, or by the computer method described Talwani and others (1959, p. 49). In the use of the t two methods, the assumption is usually made at the structure is two-dimensional; that is, the ngth of the structure can be disregarded in the culations since it is much longer than the other mensions. This should be a valid approximation much of the Ione basin.

Profile B-B′ (plate 1) is drawn across Jackson lley near Buena Vista where there are a number of ll holes that reach basement rocks and thereby ovide a means of checking the interpretation of the avity data. In this area, the amount of slate un- rlying the basin may be relatively small, because e authors know of only one drill hole (see Pask and rner, 1952, p. 31) which is reported the have en- untered rock of this type. Profile B-B′ shows a neralized geologic cross section obtained prin- ally from the drill hole data provided by Pask and rner (1952, p. 27-39) and a comparison of the sidual gravity anomaly with the anomaly culated by the use of a graticule from the geologic oss section, using a density contrast of 1.0 g/cm³. reement between the observed and the calculated omalies is reasonably good; this tends to confirm e assumed density contrast and the over-all shape the basin structure as drawn from seismic and drill le data. Profile C-C′ (plate 1) is located near smic profile d-d′, southwest of Ione. There are no ll holes that reach basement rock in the deeper ts of the basin in this area, so the geologic cross tion is based on seismic data alone. In this exam- , the correlation between observed and calculated vity anomalies is only fair. The good-to-fair suc- s of the method for these profiles suggests that it should be possible to use the gravity data in other parts of the Ione area to extend the structural information.

Gravity profiles A-A′, D-D′, E-E′, F-F′, and G-G′ are also shown on plate 1. Geologic cross sections were constructed for all of the profiles--using known basement depths from outcrops, drill holes, and seismic data where available and depths derived from gravity data between known points. The geologic sections and other available data were then used to construct a contour map of the basement rock surface (plate 1), with a contour interval of 100 feet.

The profiles and basement contour map undoubtedly reflect some of the possible errors discussed earlier. For example, gravity data alone would have led to a misinterpretation of the geology in the vicinity of profile D-D′ (plate 1), which is located near the apparent divide in the ancient basin at Indian Hill. The gravity anomaly here suggests a larger and deeper basin than actually is the case, probably because, as mentioned earlier, the basement rocks in this area have been extensively altered, resulting in a lower density. Perhaps these altered rocks represent a remnant of the pre-Ione weathered basement surface which was not eroded because of its protected location.

Seismic Data

Seismic refraction was used at three locations near Carbondale and one location southwest of Ione to determine the depth to basement rocks. A reversed refraction profile (a-a′ plate 1 and figure 3), located at a point along Dry Creek in the valley between exposures of greenstone, shows two layers with average velocities of about 2000 and 16,500 feet per second, respectively, which are interpreted to represent a thickness of about 40 feet of sand and alluvium over greenstone.

The second seismic determination (b-b′ on plate 1) was located in the southern part of sec. 28, T.7 N., R. 9 E., on the eastern side of the Ione basin. At this location, the depth to the high velocity basement layer was found to be approximately 100 feet. Farther west, near the center of sec. 30, T. 7 N., R. 9 E., (c-c′ on plate 1)—no high velocity layer was detected using a geophone spread[1] approximately 800 feet long. For this reason, the basement contour map (plate 1) indicates that the depth to greenstone should be more than 200 feet in this area.

Seismic profile d-d′ (plate 1 and figure 4), located about 1 1/2 miles southwest of Ione, is a northeast-trending line 5500 feet long, consisting of five 1100-foot-long geophone spreads, each with a detector spacing of 100 feet. Depths to bedrock were computed at each geophone by a method

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[1] The geophone spread is the total distance between the shot point and the most distant geophone in the profile. A geophone spread of at least four times the depth to be investigated is usually required in refraction work.

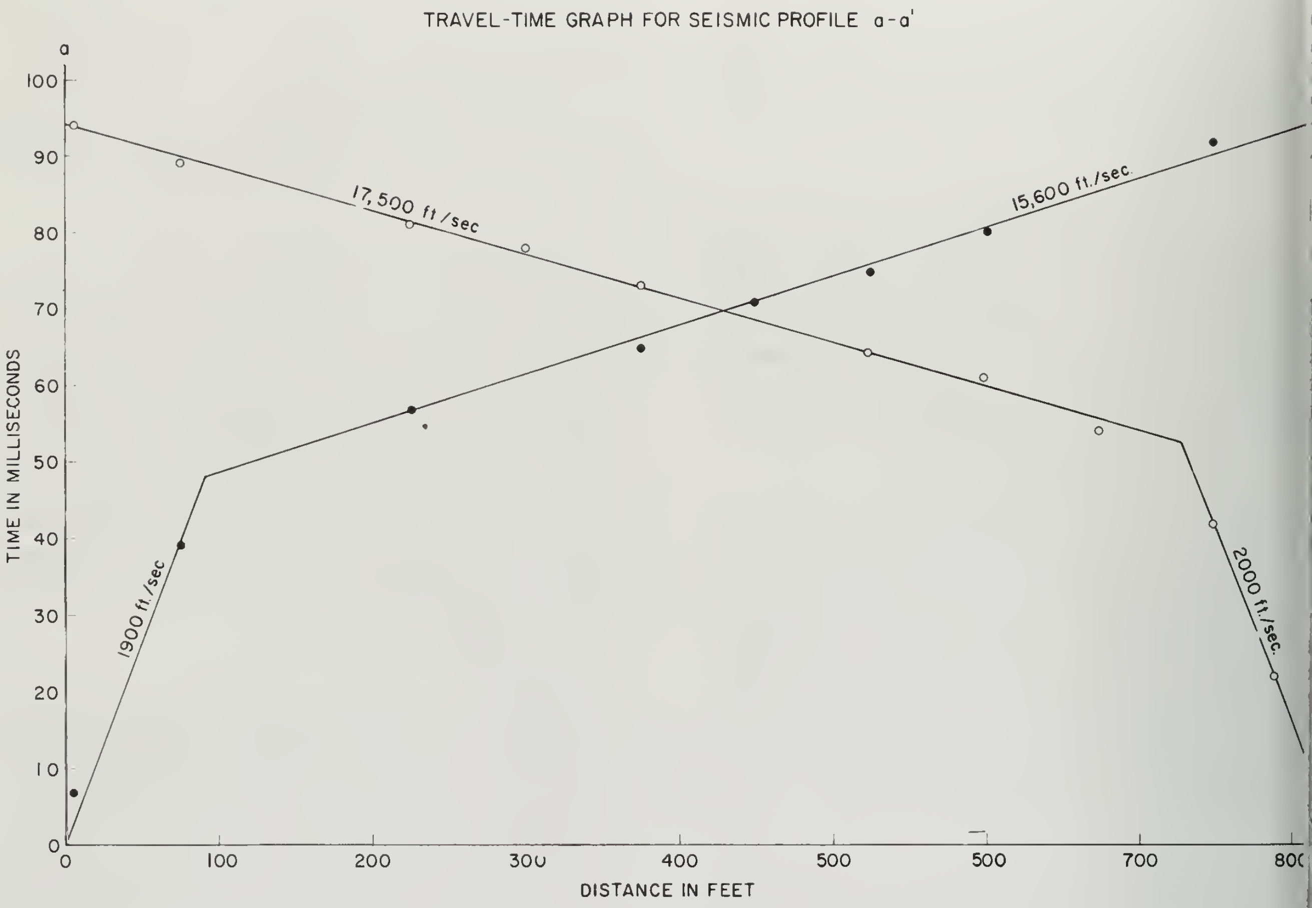

Figure 3. Travel-time graph for seismic profile a-a′.

osely similar to the time-depth method described Hawkins (1961); the time-distance plots and ismic velocity section are shown in figure 4. The locity of the principal layer (presumably Ione For- ation) overlying basement rock ranges between 00 and 6000 feet per second, except for a thin ar-surface weathered layer. The velocity of the sement rocks on this profile ranges between ,000 and 20,000 feet per second. The elevation of sement rock decreases to approximately - 190 feet the deepest part of the basin on this profile according to the seismic depth calculations.

An anomalously thick (as much as 50 feet) low locity zone consisting of two layers with velocities about 1000 and 2000 feet per second, spectively, is found between stations 4200 and 00 on the northeastern end of the profile. These yers may represent relatively unconsolidated terial which fills the site of an abandoned lignite ip-mining operation. Also, a zone of material near surface at station 3300 shows a seismic velocity about 3000 feet per second. This layer may present a relatively consolidated part of the Ione rmation or possibly a small erosional remnant of her the Valley Springs or Mehrten Formations.

The logs of four shallow drill holes located near ismic profile d-d′ were furnished by William aven of Interpace Corporation. The locations and ervals drilled are shown in figure 4, projected to plane of profile d-d′. Below the soil layer, the ill hole logs show sedimentary rocks more or less pical of the Ione Formation. None of these drill les is believed to have penetrated basement rock.

gnetic Profiles

Three east-west magnetometer traverses were de across the Ione basin to determine whether the gnetic field would indicate differences in rock pes. A Jalander flux-gate magnetometer with a sen- sivity of about 10 gammas per scale division was d for the survey. Profile X-X′ (figure 5 and plate 1 extends for about 10 miles along State Highway . Profile Y-Y′ (figure 5) extends from the junc- n of State Highway 88 and the Jackson Valley d generally eastward about 9 miles to a point nor- ast of the Pardee Reservoir. Profile Z-Z′ (figure was made along State Highway 16 from west of idge House eastward about 13 miles. Most of the k types found in the area are crossed by these files.

The only rock types from the Ione area found to ve relatively high values of magnetic susceptibility specimens of andesite tuff of the Mehrten For- tion and serpentine (table 1). Confirming these servations, the eastern part of profile X-X′ shows le distinction among the rock types traversed, ex- pt for some very minor anomalies. On the west e of this profile, the values rise, somewhat irregularly, and reach a level about 1200 gammas higher than that to the east. This anomaly probably is caused, at least in part, by volcanic rocks in the Mehrten Formation. However, a published aeromagnetic map (Meuschke and others, 1966) shows a major anomaly in this part of the Sacramento Valley. This large anomaly is undoubtedly caused by magnetic rocks in the basement underlying the valley (Griscom, 1966, p. 410-411).

Profiles Y-Y′ and Z-Z′ (figure 5) which cross basement rocks and sedimentary rocks of the Ione Formation are both nearly featureless except for sharp magnetic highs over areas of serpentine.

Although the magnetic data appear to be of little value for distinguishing among basement rock types other than serpentine, the traverses do suggest that there are no major serpentine masses in the basement rocks of the Ione area, except for those which are shown on the geologic map (plate 1).

Resistivity Soundings

Electrical resistivity soundings were made at three locations in the area primarily to determine whether or not the known lignite beds at these locations might be detected from surface electrical measurements.

A number of attempts have been made to apply resistivity methods to prospecting for lignite in other areas. The method depends on a contrast in electrical conductivity between the lignite and the surrounding beds. Heiland (1946, p. 739-740) discussed a number of examples and concluded, "If the lignite beds are soaked with mineralized waters and the overburden formations are poor conductors, fairly definite results may be obtained." These conditions may be fulfilled when glacial drift or sand, for example, overlie the better-conducting lignite. In the Ione area, however, the overburden commonly consists of clayey sand or clay, which could be expected to have a high conductivity; and the outlook for success is much less promising.

Electrical soundings were attempted at several locations (plate 1); but except possibly for one case where the lignite was at a relatively shallow depth, no evidence of the lignite was found on the sounding curves. Possibly this is because the ratio of overburden depth to thickness of lignite was relatively high in most locations. Figure 6 shows the drill hole log and a plot of apparent resistivity vs. electrode separation on double logarithmic paper for an electrical sounding at drill hole 11, in Jackson Valley, just southwest of Buena Vista.[1]

The log of the drill hole shows, from the surface down, 6 feet of brown soil, 13 feet of gravel, 2 feet of clay, and 10 feet of lignite underlain by clay. The

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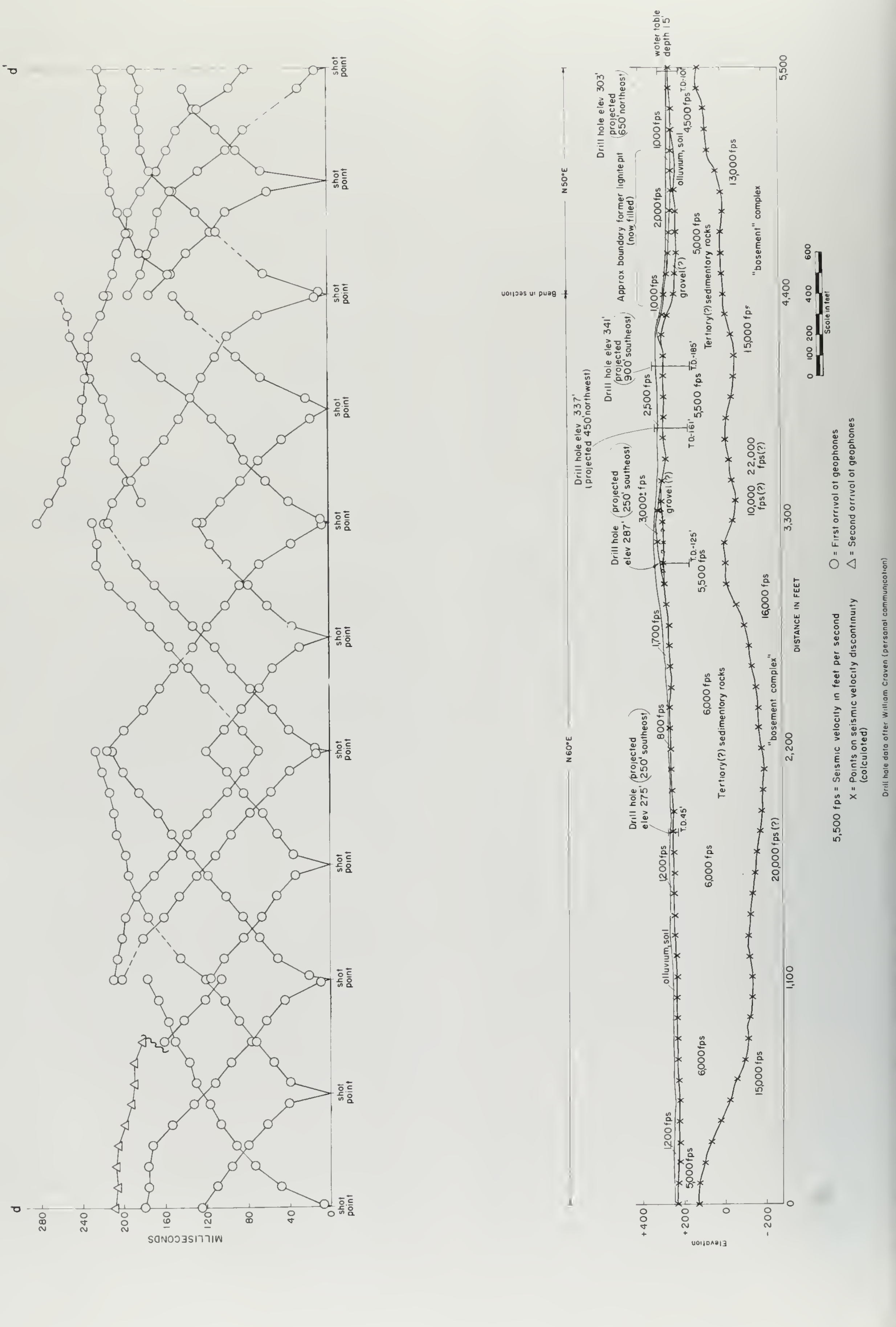
[1] Drill hole log presented through the courtesy of Joseph De Angelis of the American Lignite Products Company (now American Lignite Products Division of Interpace).


d
d'
MILLISECONDS
0
40
80
120
160
200
240
280
shot point
Elevation
+400
+200
0
-200
DISTANCE IN FEET
0
1,100
2,200
3,300
4,400
5,500
N60°E
N50°E
Bend in section
5,000fps
1200fps
6,000fps
15,000fps
alluvium, soil
1200fps
6,000fps
20,000fps(?)
Drill hole elev 275' (projected 250' southeast)
T.D.45'
Tertiary(?) sedimentary rocks
800fps
6,000fps
"basement" complex
1,700fps
16,000fps
Drill hole elev 287' (projected 250' southeast)
3,000± fps
gravel(?)
T.D.-125'
5,500 fps
10,000 fps(?)
22,000 fps(?)
Drill hole elev 337' (projected 450' northwest)
T.D.-161'
2,500fps
Drill hole elev 341' (projected 900' southeast)
T.D.-185'
5,500 fps
15,000 fps
1,000fps
gravel(?)
Tertiary(?) sedimentary rocks
5,000fps
Approx boundary former lignite pit (now filled)
2,000fps
"basement" complex
1,000fps
alluvium, soil
13,000fps
4,500fps
T.D.-10'
Drill hole elev 303' projected 650' northeast
water table depth 15'
0 100 200 400 600
Scale in feet
5,500 fps = Seismic velocity in feet per second
X = Points on seismic velocity discontinuity (calculated)
○ = First arrival at geophones
△ = Second arrival at geophones
Drill hole data after William Craven (personal communication)

sistivity sounding at this location was interpreted ing the album of theoretical curves from Mooney d Wetzel (1956). Interpretation yields two layers, e uppermost with a resistivity of about 160 ohm-et, underlain at a depth of about 23 feet by a layer th a resistivity of about 130 ohm-feet. The second layer agrees quite well with the known depth of the lignite, but it does not have a very distinct resistivity contrast. Thus, it is clear that detection of lignite beds in this area by surface electrical resistivity methods would probably be very difficult except under ideal conditions.

RESULTS OF DRILLING

During the course of the investigation of the ne area, three core holes were drilled under a operative program by the California Division of ines and Geology and the U.S. Bureau of Mines. ne of the purposes of this drilling program was to st the structural interpretations based on the ophysical data. The holes were drilled both to the rth and south of the presently producing clay, nd, and lignite properties in relatively unexplored rts of the basin (see plate 1). These are areas in hich the gravity and seismic data indicate that subantial thicknesses of Tertiary sedimentary rocks uld be expected. All of the holes were cored conuously from near the surface into relatively fresh sement rock. A graphic representation and brief hologic description of the rock types encountered these holes are given in figure 7.

Hole 1967-1 (figure 7), drilled 2 miles norwest of Carbondale in the NE 1/4 of sec. 30, T. 7 ., R. 9 E., penetrated rocks typical of the Ione Foration from the surface to a depth of 193 feet. elatively pure clays of possible commercial value ere encountered in the upper 50 feet of the hole. ds of lignite were cored between 50 and 75 feet d between 113 and 161 feet. Green claystone and ht gray sandstone, probably equivalent to the pre-ne beds, were encountered from 193 feet to the p of the basement at 251 feet. The upper 10 feet of e basement is weathered and is composed of a sidual green claystone. This grades downward into medium dark green, feldspathic and tuffaceous etasandstone which may represent part of the Conmnes Formation. The total depth of the hole is 3 feet.

Hole 1967-2 (figure 7) was drilled south of ena Vista Peaks in the SW 1/4 of the NE 1/4 of c. 30, T. 5 N., R. 10 E. The well spudded in sandne and conglomerate composed of pebbles of artz, chert, metamorphic, and volcanic rocks. any of the volcanic rock clasts in the conglomerate d some of the sand grains are magnetic, a characristic of the Mehrten Formation. The Valley rings Formation was encountered at 68.6 feet. It nsisted of gray, pale green, and buff to brown ndstone and sandy claystone. Beds of the Ione Foration were penetrated from 118.6 feet to the top of e weathered basement at 752.4 feet, a total of 3.8 feet. The Ione Formation is characterized by a gh proportion of sandstone and clayey sandstone. rbonaceous material is common, but only a few ry thin lignitic seams were encountered. The top of e hard unweathered basement, composed of metasedimentary and metavolcanic rocks, is at 764.7 feet. No rocks corresponding to the pre-Ione beds were recognized in this hole.

Hole 1967-3 (figure 7) was drilled in the northern part of the Ione basin, halfway between Bridge House and Carbondale in the NE 1/4 sec. 13, T 7 N., R. 8 E. The upper 90 feet of rocks penetrated in this hole consist of light gray to yellowish sandstone and green bentonitic claystone of the Valley Springs Formation. The Ione Formation was encountered between 90 and 359 feet. It consists of light gray claystone and sandy claystone commonly stained buff-brown or red by iron oxide. Carbonaceous claystone beds were logged between 112 feet and 154 feet and between 221 feet and 228 1/2 feet, but no significant thicknesses of lignite were found. Green silty, sandy claystone, probably representing the pre-Ione beds, was cored from 359 feet to 425 feet. Twelve and a half feet of blue-gray sandstone including about 1 (one) foot of basal quartz pebble conglomerate overlies the weathered basement which was encountered at 437.3 feet. The hole penetrated weathered greenstone to a total depth of 455 feet.

All three core holes encountered thick sequences of Tertiary sedimentary rocks before reaching the pre-Cenozoic basement complex. The northernmost hole, 1967-3, penetrated 437 feet of these sedimentary rocks; and the southernmost hole, 1967-2, 752 feet. The corresponding elevations of the basement rocks for these two holes are -192 feet and -250 feet, respectively. These basement depths tend to confirm the presence of a subsurface northwest-southeast trending basin system, as outlined by the geophysical data. Hole 1967-1 is believed to be on the eastern flank of a buried greenstone ridge northwest of Carbondale. In this hole, the basement rocks were encountered at a depth of 251 feet (elevation -33 feet), considerably higher than in the others which, judging from the geophysical data, are located nearer to the axis of the basin.

Holes 1967-1 and 1967-3 encountered sequences of sedimentary rocks directly above the basement that differ in physical appearance from the rocks of the Ione Formation. These older rocks, which underlie the Ione Formation, do not appear to have been subjected to the high degree of weathering associated with the Ione. For this reason, they may be equivalent to the pre-Ione beds described by Pask and Turner (1952, p. 15 and 16) in the Buena Vista area. The absence of these beds from hole 1967-2

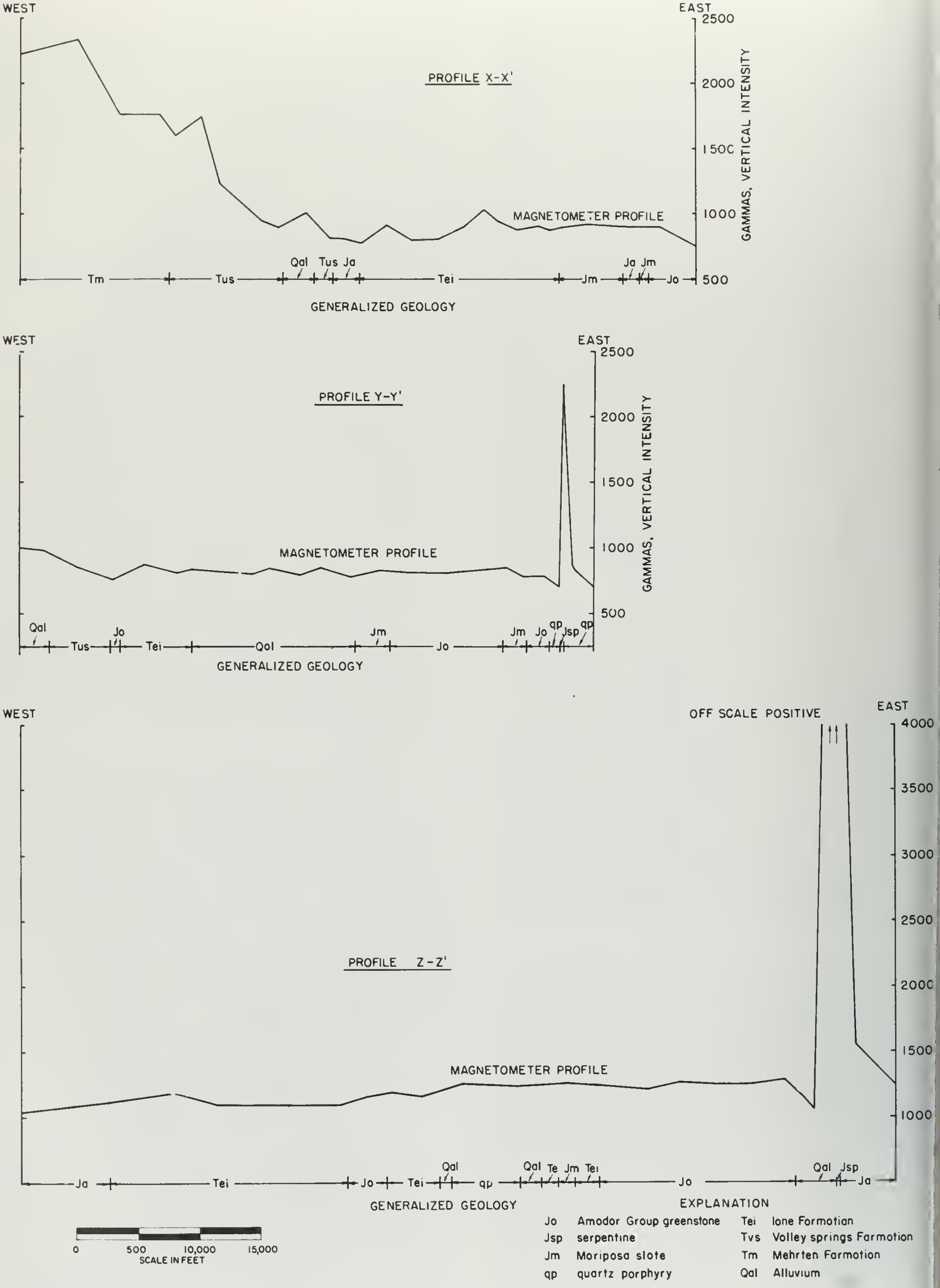
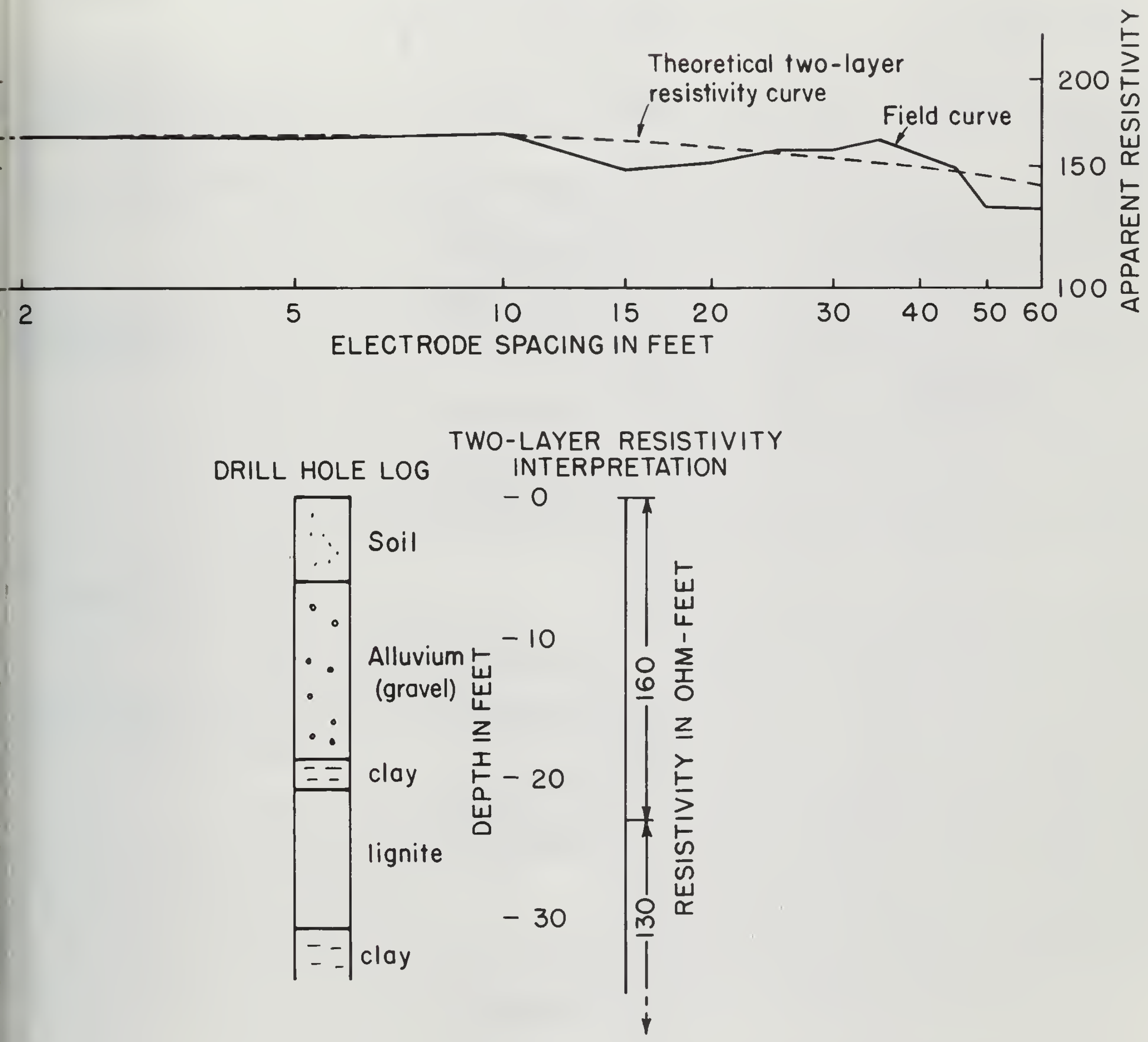


Figure 5. Magnetic profiles X-X′, Y-Y′, and Z-Z′ showing generalized geology.



ure 6. Resistivity sounding, interpretation, and log of drill hole 11.

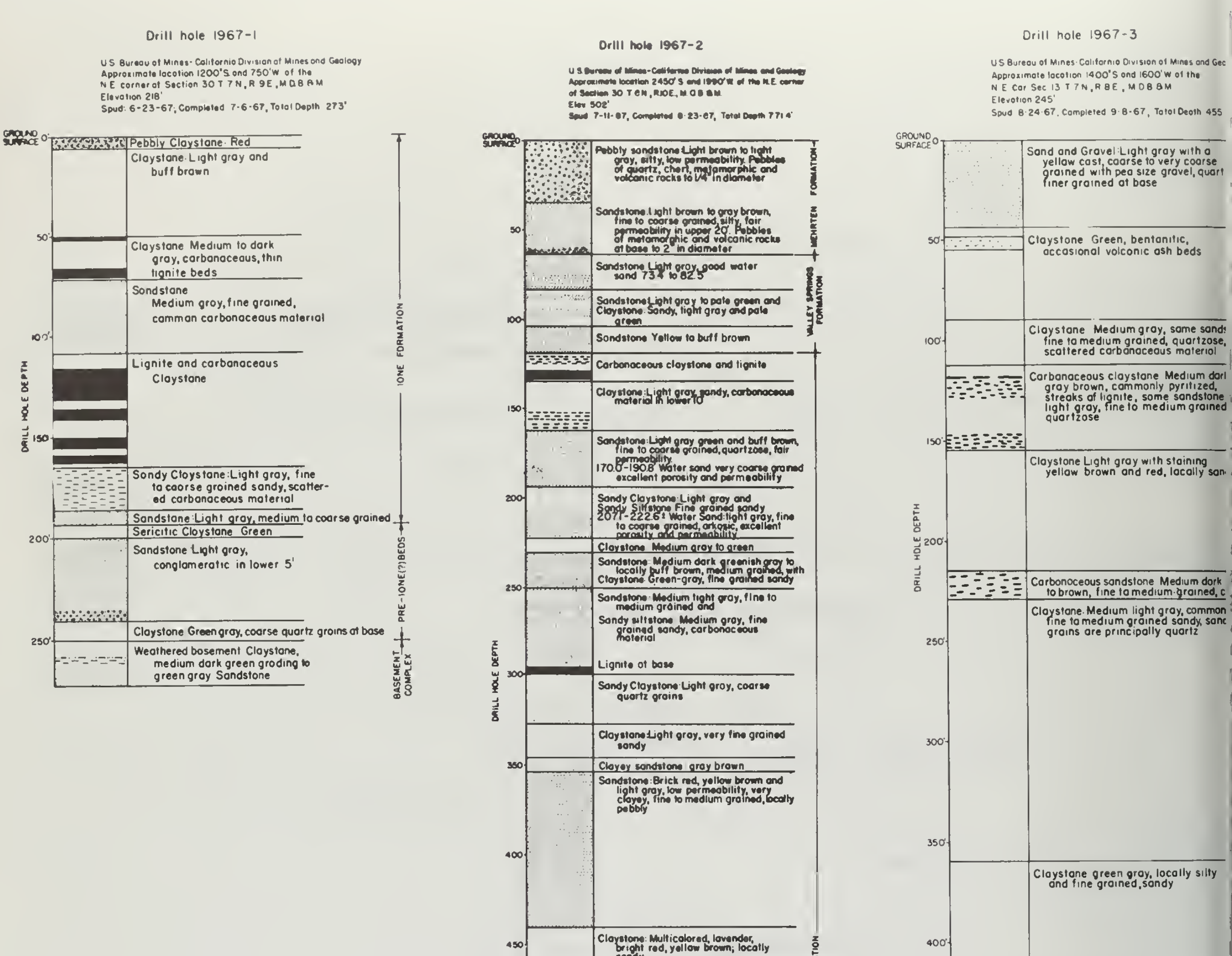

Drill hole 1967-1
U S Bureau of Mines- California Division of Mines and Geology
Approximate location 1200'S. and 750'W of the
N E corner of Section 30 T 7 N, R 9E, M D B & M
Elevation 218'
Spud: 6-23-67; Completed 7-6-67, Total Depth 273'
GROUND SURFACE
0'
50'
100'
150
200'
250'
DRILL HOLE DEPTH
Pebbly Claystone· Red
Claystone· Light gray and buff brown
Claystone Medium to dark gray, carbonaceous, thin lignite beds
Sandstone Medium gray, fine grained, common carbonaceous material
Lignite and carbonaceous Claystone
Sandy Claystone: Light gray, fine to coarse grained sandy, scattered carbonaceous material
Sandstone: Light gray, medium to coarse grained
Sericitic Claystone Green
Sandstone Light gray, conglomeratic in lower 5'
Claystone Green gray, coarse quartz grains at base
Weathered basement Claystone, medium dark green grading to green gray Sandstone
IONE FORMATION
PRE-IONE(?) BEDS
BASEMENT COMPLEX
Drill hole 1967-2
U S Bureau of Mines-California Division of Mines and Geology
Approximate location 2450' S and 1990' W of the N.E. corner of Section 30 T 6N, R10E, M D B & M.
Elev 502'
Spud 7-11-67, Completed 8-23-67, Total Depth 771.4'
GROUND SURFACE
0
50
100
150
200
250
300
350
400
450
500
350
600
650
700
750
DRILL HOLE DEPTH
Pebbly sandstone: Light brown to light gray, silty, low permeability. Pebbles of quartz, chert, metamorphic and volcanic rocks to 1/4" in diameter
Sandstone: Light brown to gray brown, fine to coarse grained, silty, fair permeability in upper 20'. Pebbles of metamorphic and volcanic rocks at base to 2" in diameter
Sandstone Light gray, good water sand 73.4 to 82.5
Sandstone: Light gray to pale green and Claystone: Sandy, light gray and pale green
Sandstone Yellow to buff brown
Carbonaceous claystone and lignite
Claystone: Light gray, sandy, carbonaceous material in lower 10
Sandstone: Light gray green and buff brown, fine to coarse grained, quartzose, fair permeability.
170.0-190.8 Water sand very coarse grained excellent porosity and permeability
Sandy Claystone: Light gray and Sandy Siltstone Fine grained sandy
207.1-222.6± Water Sand: light gray, fine to coarse grained, arkosic, excellent porosity and permeability
Claystone Medium gray to green
Sandstone: Medium dark greenish gray to locally buff brown, medium grained, with Claystone· Green-gray, fine grained sandy
Sandstone· Medium light gray, fine to medium grained and
Sandy siltstone Medium gray, fine grained sandy, carbonaceous material
Lignite at base
Sandy Claystone· Light gray, coarse quartz grains
Claystone: Light gray, very fine grained sandy
Clayey sandstone gray brown
Sandstone: Brick red, yellow brown and light gray, low permeability, very clayey, fine to medium grained, locally pebbly
Claystone: Multicolored, lavender, bright red, yellow brown; locally sandy
Sandstone: Light yellow brown, fine to very coarse grained, quartzose
Pebbly sandstone Light gray, clayey
Clayey sandstone Light yellow to light brown and gray, fine to medium grained to locally medium to coarse
Sandstone Medium gray, scattered carbonaceous material, fine to medium grained somewhat silty
Carbonaceous siltstone Medium gray to black
Interbedded clayey sand, silty sand, Sandy Siltstone, Siltstone and Claystone Medium to dark gray, common carbonaceous material
Pebbles of weathered greenstone at base
Claystone Dark green
768.7' Fresh greenstone
MEHRTEN FORMATION
VALLEY SPRINGS FORMATION
IONE FORMATION
BASEMENT COMPLEX
Drill hole 1967-3
U S Bureau of Mines· California Division of Mines and Gec
Approximate location 1400'S and 1600'W of the
N E Cor Sec 13 T 7 N, R 8 E, M D B & M
Elevation 245'
Spud 8·24·67, Completed 9·8-67, Total Deoth 455
GROUND SURFACE
0
50'
100'
150'
200'
250'
300'
350'
400'
450'
DRILL HOLE DEPTH
Sand and Gravel: Light gray with a yellow cast, coarse to very coarse grained with pea size gravel, quart finer grained at base
Claystone Green, bentonitic, accasional volcanic ash beds
Claystone Medium gray, some sands fine to medium grained, quartzose, scattered carbonaceous material
Carbonaceous claystone Medium dar gray brown, commonly pyritized, streaks of lignite, some sandstone light gray, fine to medium grained quartzose
Claystone Light gray with staining yellow brown and red, locally san
Carbonaceous sandstone Medium dark to brown, fine to medium-grained, c
Claystone· Medium light gray, common fine to medium grained sandy, sanc grains are principally quartz
Claystone green gray, locally silty and fine grained, sandy
Sandstone Light gray, pebbles of quartz
Weathered greenstone

Figure 7. Graphic logs of CDMG-USBM core holes (3).

ggests that a period of erosion followed the position of the pre-Ione sedimentary rocks.

None of the holes encountered laterite, which is own to have formed in the basin area as a result of e intense chemical weathering of the basement (Pask and Turner, 1952, p. 14). It is likely that basement rocks in holes 1967-1 and 1967-3 were protected from this weathering by a covering of the pre-Ione beds. Erosion may have removed the laterite, if any was formed, in the vicinity of hole 1967-2.

GEOLOGIC INTERPRETATION

Analysis of the gravity maps and profiles given the preceding sections indicates that the sedimen- ry rocks of the Ione Formation were deposited in a sin or valley extending from south of Michigan r on the north to the Buena Vista Peaks area on e south. This basin is bounded on the west by a sistant greenstone ridge which is represented by e outcrops of greenstone west of Ione and nor- west of Buena Vista. Interruptions in the ridge, ssibly outlets for the Eocene streams, are ggested in three places by the gravity data utheast of Bridge House, Jackson Valley, and uthwest of Buena Vista Peaks (see plate 1). The ird of these, a particularly distinct anomaly just rth of the Mokelumne River, indicates a structural erosional feature that extends into the Great lley for some distance; this suggests the location a major buried drainage system. The gravity data so suggest that there was a divide in the buried sin northwest of Ione, near Indian Hill, which parates the basin into two parts.

The Ione basin appears to have an asymmetrical ape, generally with a gentle eastern slope and a ore abrupt western flank, particularly in the uthern half of the area. The high relief associated th the greenstone ridge and Ione basin could have sulted in part from faulting but is probably imarily an erosional feature.

Lindgren (1911, p. 195-213) discussed the Ter- ry history of the Jackson and Big Trees adrangles, including the Ione area, and showed e distribution of the auriferous deposits of the Ter- ry streams. According to Lindgren's map (1911, ate 1), the Tertiary Mokelumne River flowed west- rd through the present site of the town of ymouth and entered the Ione area somewhere rth of Carbondale and south of State Highway 16. e divide in the Ione basin near Indian Hill may ve separated the northern ancestral Mokelumne ver drainage from another westward-flowing ainage system in the south. In Eocene time, the ne basin valley was filled with sediments of the ne Formation. Tropical conditions at this time may ve been a reason for the accumulation of large antities of vegetation represented by the lignite ds. These conditions were also responsible for the gh degree of weathering of the basement rocks, the velopment of lateritic soils, and the formation of e high-purity clays and high-silica sands found in e Ione Formation (Allen, 1929, p. 354).

Eventually the sediments filled the basin and covered all but possibly the highest points on the confining ridges. When the basin became filled, the newly established drainage found numerous outlets thus changing conditions of sedimentation. It appears that the important lignite and clay beds are mostly found at elevations below the top of the greenstone ridge. Piper and others (1939, p. 82) remarked: "The thickest coal beds are found in basins that are bounded on the east by pre-Cretaceous crystalline rocks in the Sierra Nevada foothills and on the west by outlying parallel ridges of the same rocks."

Deposits of sedimentary rocks of the Ione Formation may have covered limited areas east of the known limits of the Ione basin; but, if they did, most of them have since been removed by erosion. Evidence for this are the deposits along the Mother Lode belt in the vicinity of the towns of Jackson and Sutter Creek (Taliaferro, 1949).

Turner (1894, p. 4) reported a bore hole made many years ago at the location of Coal Mine No. 3, north of Clarksona siding on the Southern Pacific Railroad, which was said to have penetrated 800 feet of sandy clay below the coal horizon. This information has been reported in most of the subsequent literature on the area. Gale (Piper and others, 1932, p. 82) questioned the validity of this record, however, on geologic evidence. The gravity study also suggests that this is an unreasonable figure because such a thickness of sedimentary rock of Tertiary age should produce a much larger gravity anomaly than that actually observed. Plate 1 shows the estimated basement surface in this area at about present-day sea level in the center of the basin. This interpretation indicates approximately 200 feet of sedimentary rock below the coal bed.

LIGNITE

Plate 1 shows the important known lignite mines and prospects and their relationship to the basement structure in the Ione area. All of the mines, except the Interpace mines at Ione and near Indian Hill, are inactive at this time. Although some lignite is nearly always found in the Ione Formation, the locations shown indicate areas where the lignite reaches possible commercial thicknesses.

The locations of the known lignite deposits, as shown on Plate 1, indicate that the deposits in the area south of Ione are all on the eastern side or slope of the basin; those near Carbondale in the northern part of the area are mostly on the western side. Few of the deposits appear to be at or near the axis of the basin in the deeper parts although exploration may not have tested these areas thoroughly. This relationship may indicate that the thick accumulations of the vegetation, which was the source material for the lignite, occurred principally along the margins of the basin and that the most favorable locations varied from one side of the valley to the other.

The observed relationship between the basement structure and the locations of the lignite deposits suggests other parts of the Ione basin where lignite might be found. Areas between known lignite deposits such as between Buena Vista and Ione and south of Buena Vista, on the east side of the basin, and both north and south of the Carbondale area, on the west side, might be of interest because of the continuation of the basin structure in these directions.

CLAY, SAND, LATERITE, AND GRAVEL

The basement contour map, by revealing the extent and configuration of the basin, may also be of use as a general guide in the exploration for c sand, laterite, and possible auriferous gr deposits in, and possibly beneath, the Ione mation. It is reasonable to assume that deposit these commodities occur in the less explored p of the Ione basin such as north of Carbondale south of Buena Vista. Some of the sand and gr units in the basin might also have another valu a source of water.

Evidence from drill holes in the Ione b (Pask and Turner, 1952, p. 15) suggests that change to a tropical climate which resulted in formation of laterite occurred subsequent to deposition of the pre-Ione beds. This laterite w be expected to form on the basement rocks a the margin of the basin at an elevation higher the top of the pre-Ione beds. The western flan the basin would appear most favorable for the mation and retention of laterite deposits as it have been better protected from erosion than eastern flank.

CONCLUSIONS

A combination of gravity and seismic refraction methods was found to be effective for determining the depth to the basement complex in the Ione area. Using data generated by these methods, it was possible to construct a map showing the approximate configuration of the basement rock surface. This general configuration was confirmed by three holes drilled on the basis of the geophysical data.

A knowledge of the configuration of the basement rock surface is important because this is one of the factors that controlled the deposition of the Tertiary sedimentary rocks, including some of the important mineral commodities which are found within the Ione Formation. For example, the principal known lignite deposits appear to be loc near the margins of the basin, laterite deposits be found on or near buried basement ridges, sand and gravel units found in the deeper par the basin may be possible sources of water or pl gold.

Magnetic data were not used to outline s tures in the basement rocks in this area but found to be useful in locating certain rocks anomalous magnetic properties, such as serpe or volcanic rocks of the Mehrten Forma Resistivity methods were found to be of dou value in detecting lignite beds but might be use other problems such as locating shallow deposi clay or sand.

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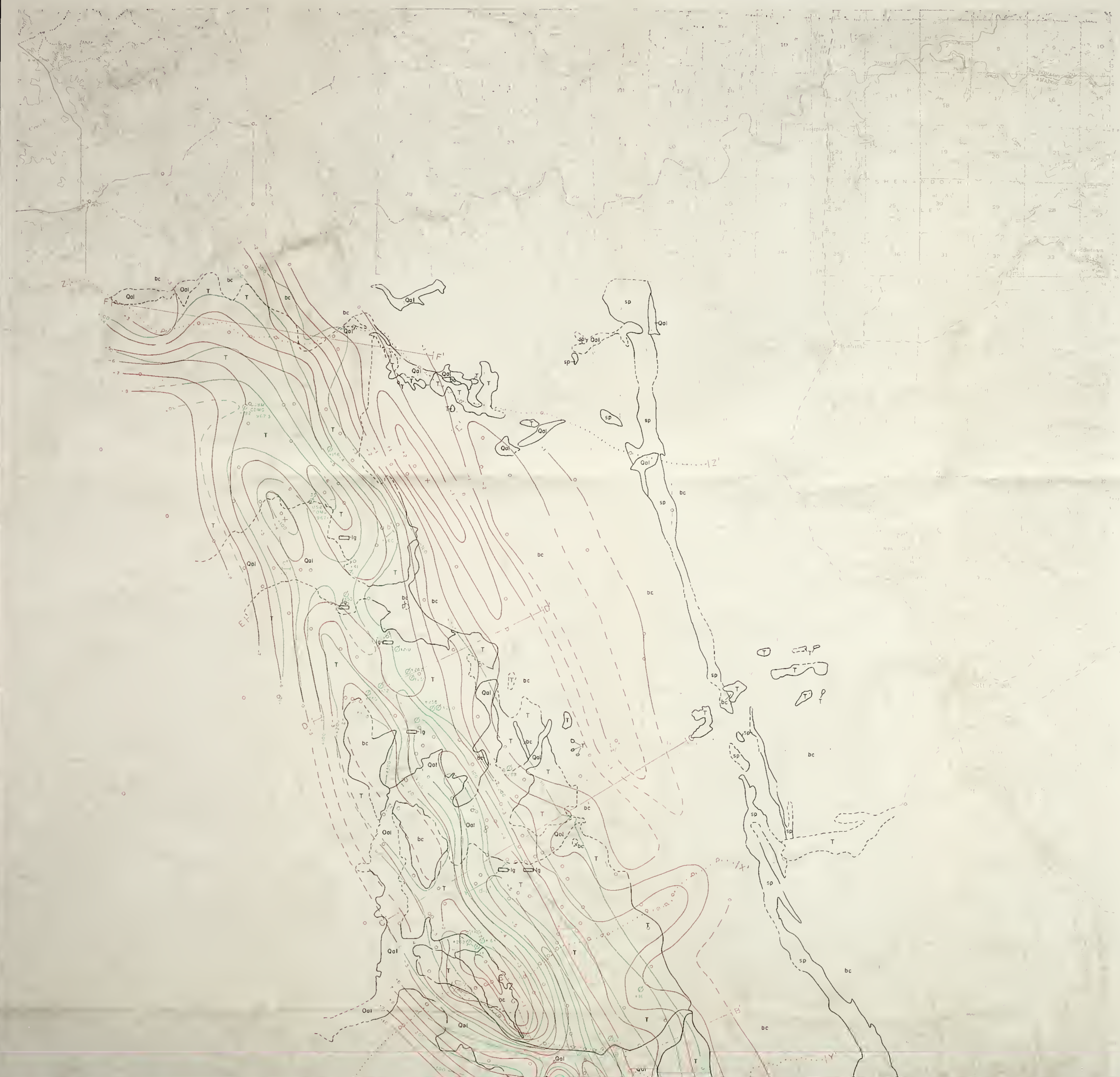

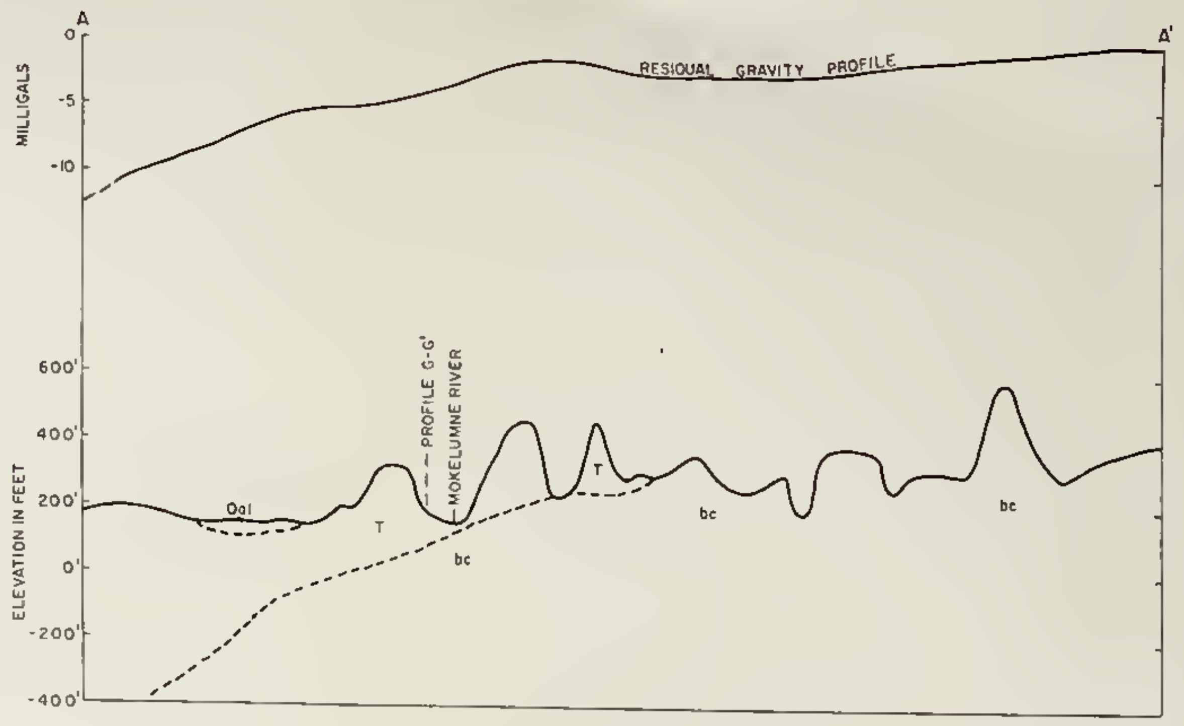

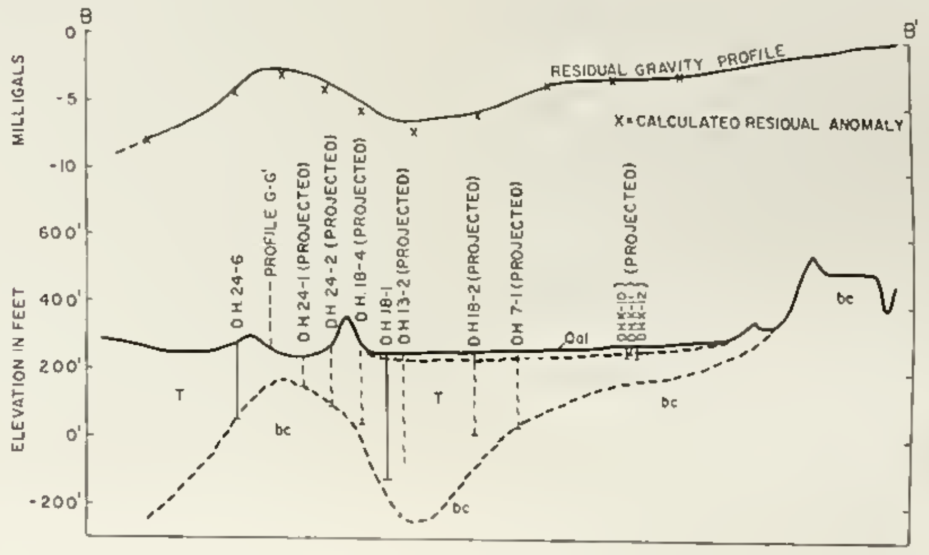

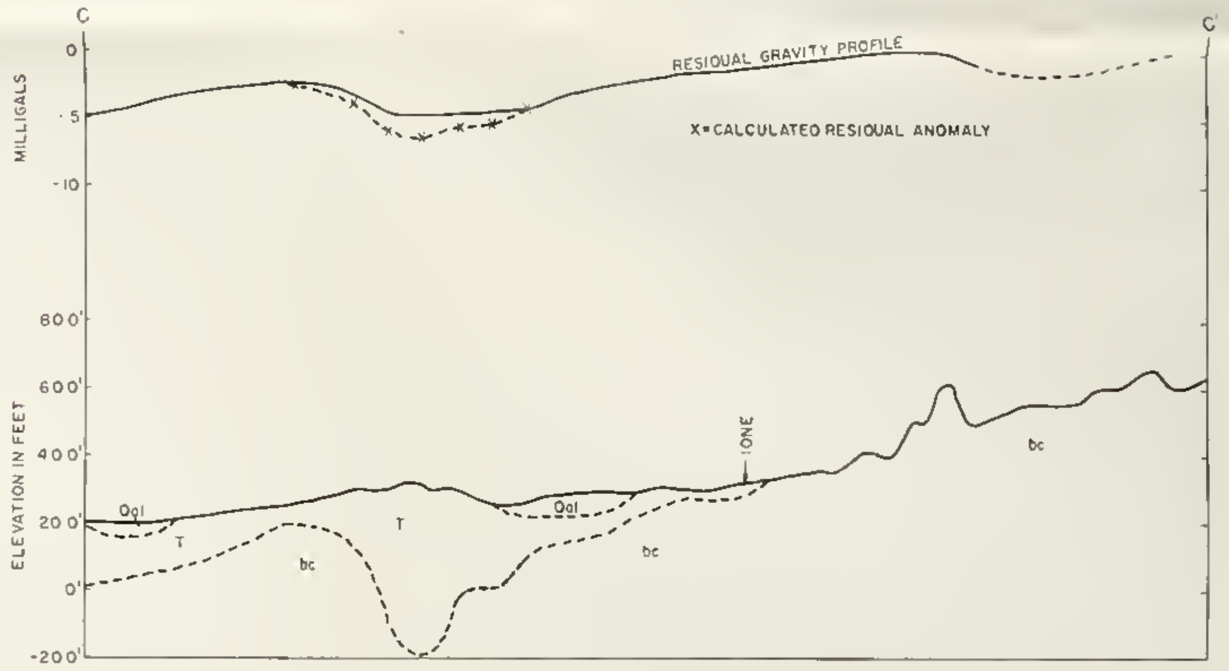

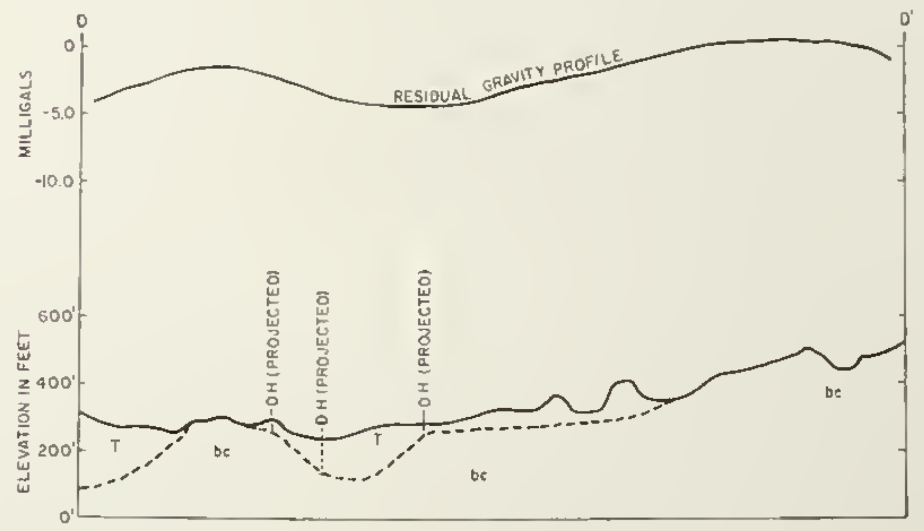

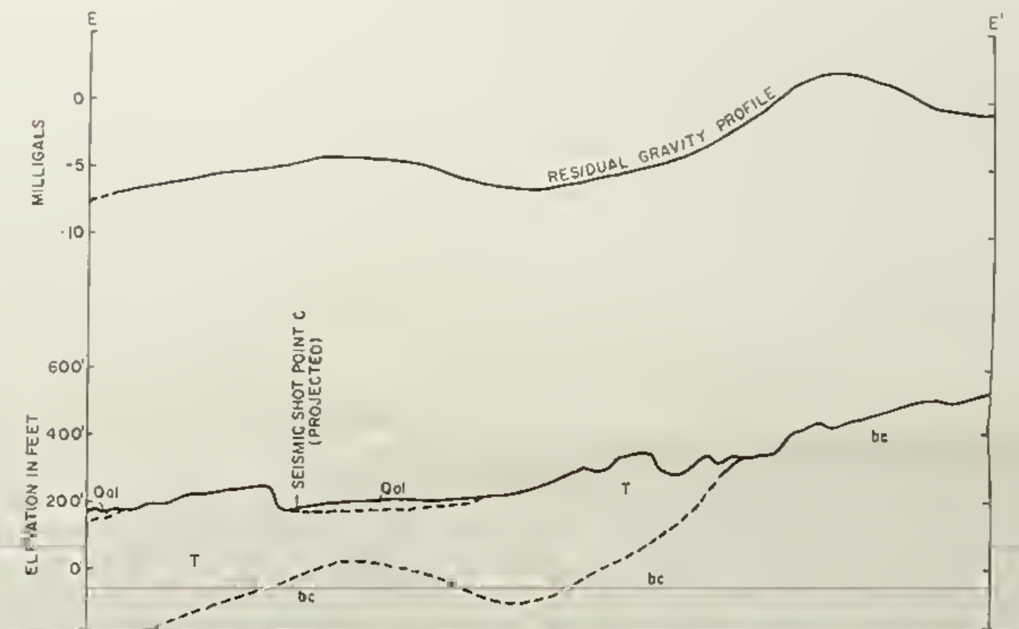

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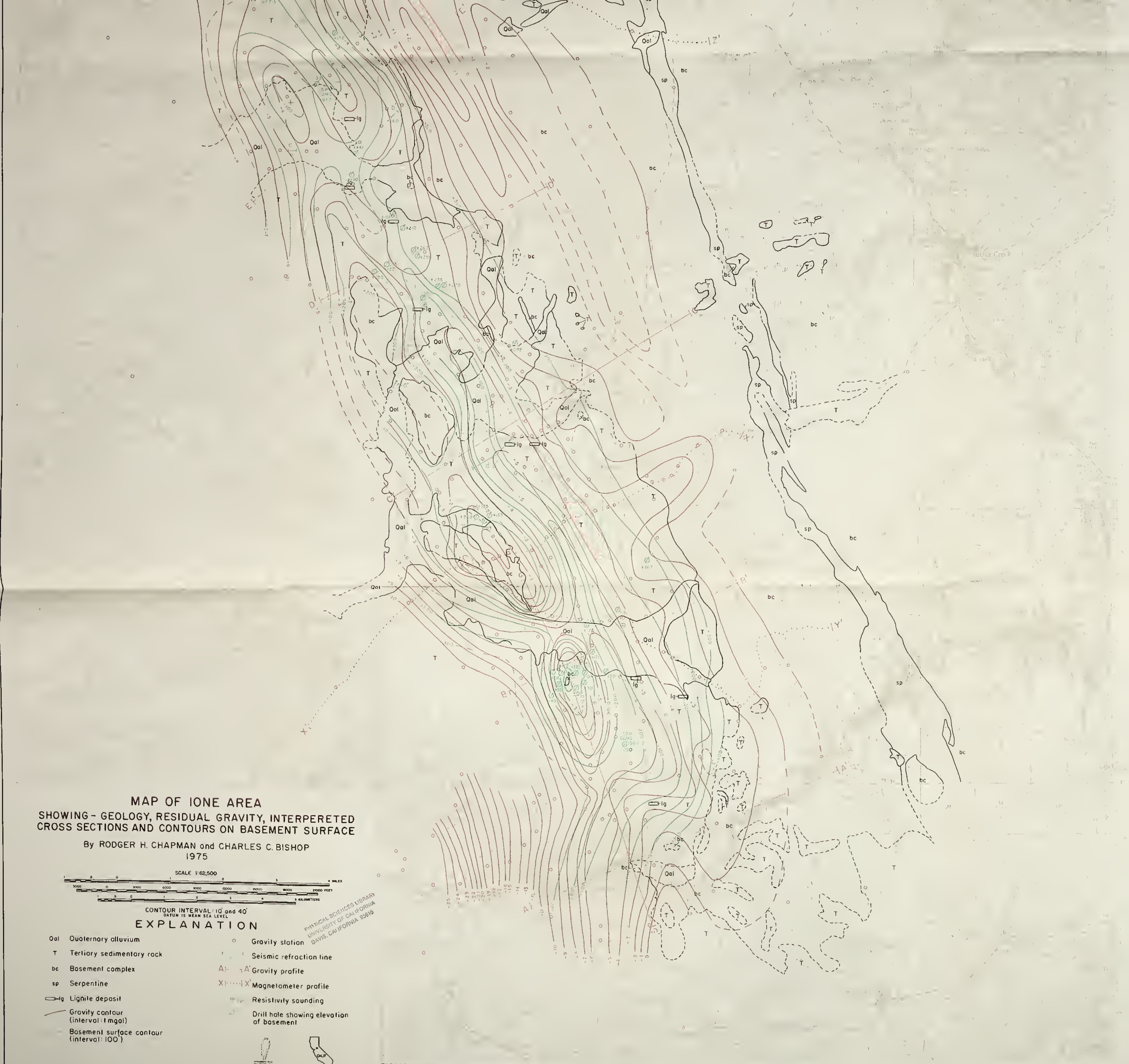

MAP OF IONE AREA

SHOWING - GEOLOGY, RESIDUAL GRAVITY, INTERPERETED CROSS SECTIONS AND CONTOURS ON BASEMENT SURFACE

By RODGER H. CHAPMAN and CHARLES C. BISHOP

1975

SCALE 1:62,500

CONTOUR INTERVAL: 10' and 40'
DATUM IS MEAN SEA LEVEL

EXPLANATION

Qal	Quaternary alluvium
T	Tertiary sedimentary rock
bc	Basement complex
sp	Serpentine
▭–lg	Lignite deposit
—	Gravity contour (interval: 1 mgal)
—	Basement surface contour (interval: 100')
○	Gravity station
	Seismic refraction line
A⊢ ⊣A'	Gravity profile
X⊢····⊣X'	Magnetometer profile
	Resistivity sounding
	Drill hole showing elevation of basement

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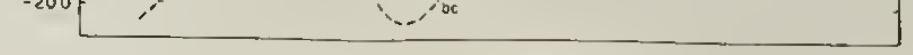
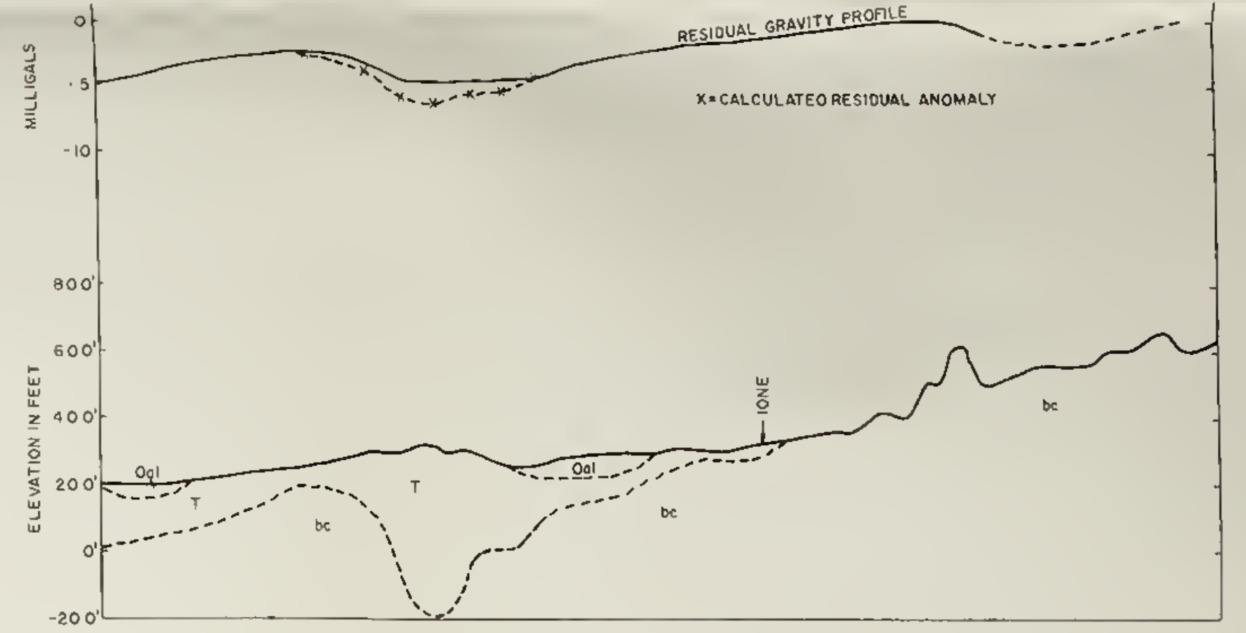
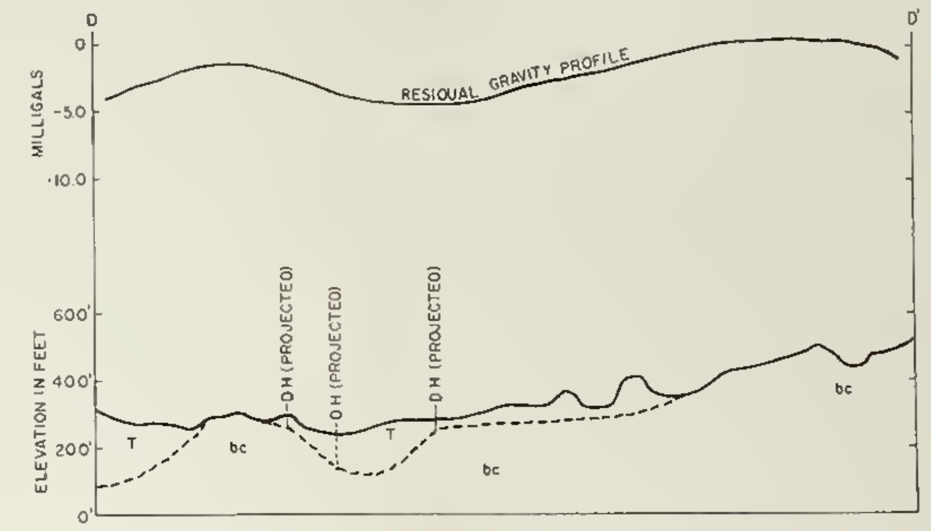
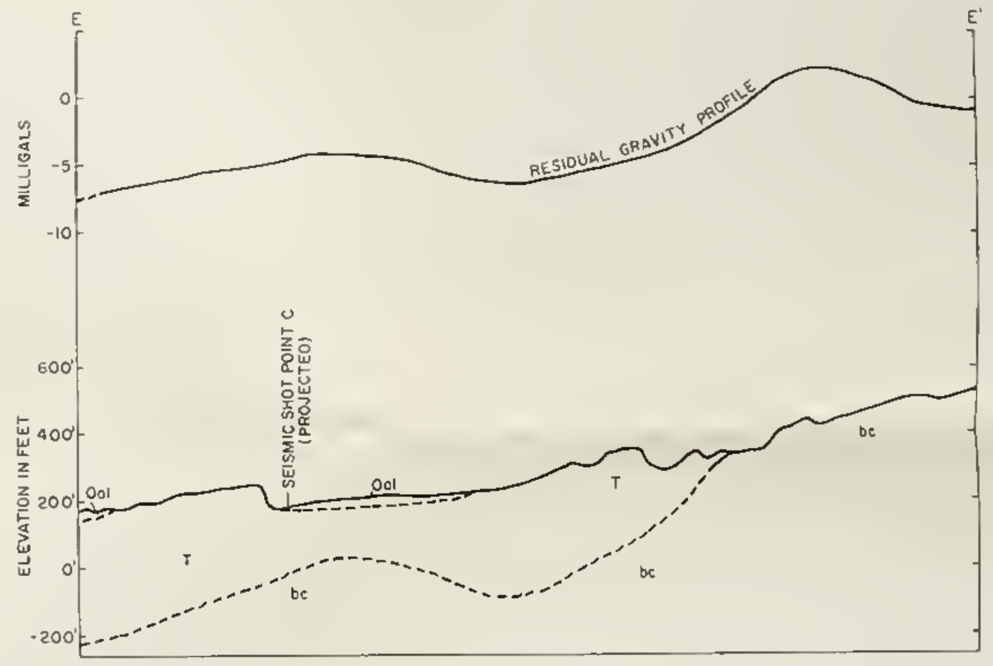
GEOLOGY MODIFIED FROM PIPER AND OTHERS (1939, PLATE 1) AND TALIAFERRO (1949)

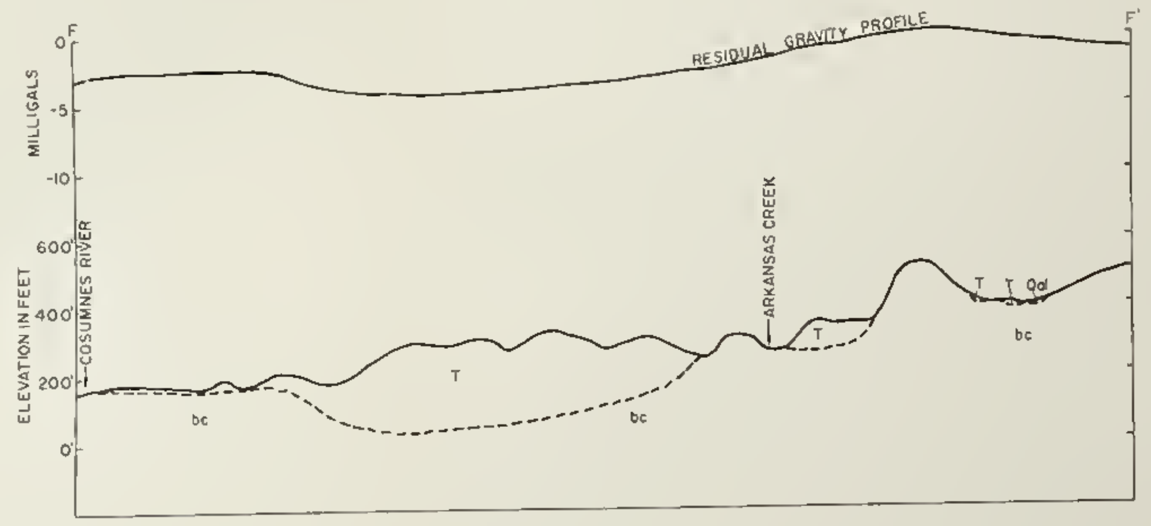
TOPOGRAPHIC BASE BY U.S. GEOLOGICAL SURVEY
This map is a reduction of 1:24,000-scale published maps

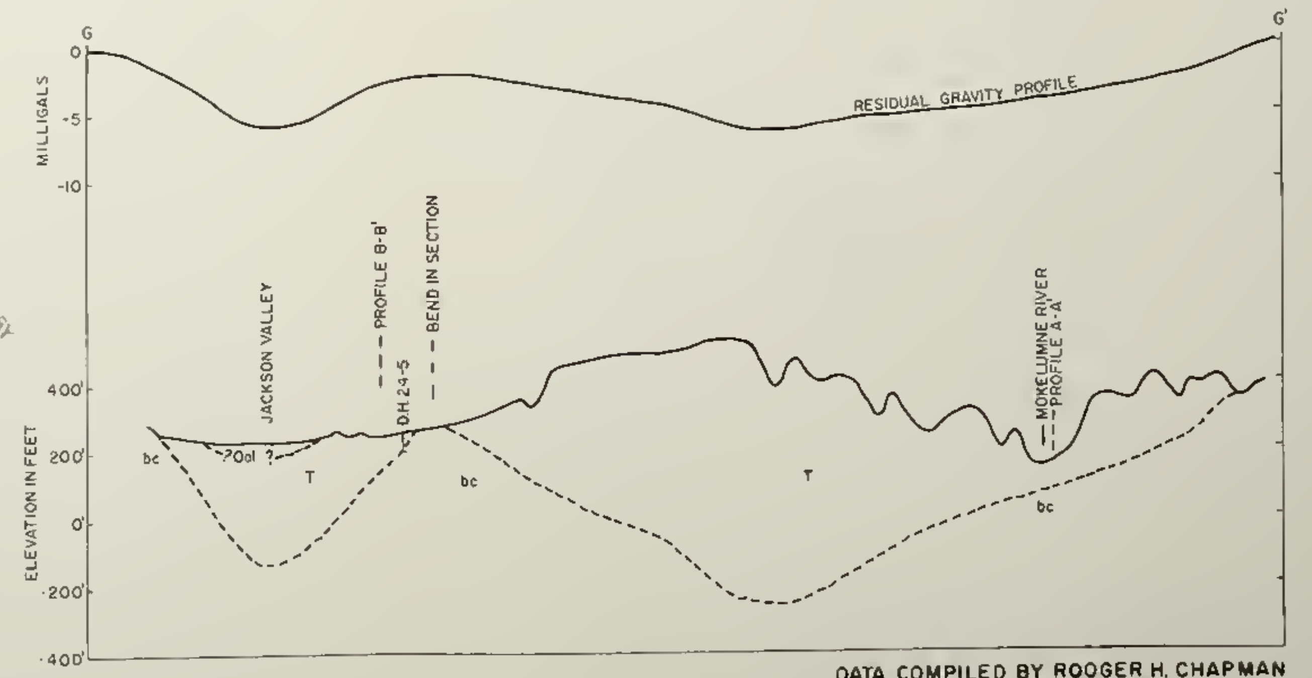












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